

# CHAPTER ONE— INTRODUCTION

## History of the Assessment

*“The impacts of the 1997–1998 El Niño are fresh in our minds, and the latest reports from the work of the Intergovernmental Panel on Climate Change (IPCC) confirm what all of you already know— changes in climate matter to individuals, communities, businesses and governments who call islands home. Your valuable natural resources, traditional ways of life, critical economic sectors, community support infrastructure, and, to a great extent, your future, depend on developing an effective response to the challenges presented by climate variability and change.” (Morrison, 2000)*

With these words, Dr. Charles Morrison, President of the East-West Center, welcomed participants to the “Workshop on Climate and Island Coastal Communities” convened in November 2000. The Workshop was part of a Pacific Islands Regional Assessment of the Consequences of Climate Variability and Change (the Pacific Assessment, or, the Assessment).

Set in motion with a similar workshop in March 1998, the Pacific Assessment began with a recognition of the significant effects that year-to-year climate variability has on communities in the region today; an example is the effect of the El Niño-Southern Oscillation (ENSO) cycle on rainfall, tropical storms and fisheries in the Pacific. The Assessment also acknowledged the importance of scientific research in the Pacific Region to understanding the nature and consequences of climate variability and change (see definitions in

the box below). Such research includes long-term monitoring of greenhouse gases at sites like Mauna Loa in Hawai‘i; studies of the regional and global influence of Pacific ocean-atmosphere processes such as ENSO; and studies of the ocean’s role in the carbon cycle, as well as the region’s significance in terms of biodiversity and endangered species.

Finally, the Pacific Assessment was an effort to build on the leadership of the Pacific Region in establishing and sustaining a critical dialogue on climate variability and change among scientists, businesses, governments and community leaders. Elements of this dialogue include the role of Pacific Island governments and regional organizations in raising international awareness of the potential consequences of climate change, as well as the success of innovative programs like the Pacific ENSO Applications Center (PEAC), which is designed to facilitate use of emerging climate forecasting capabilities to support decision-making.

This report summarizes the key findings and recommendations of the Pacific Assessment, a study of climate effects and response options for Pacific Island jurisdictions that was conducted as a regional contribution to the first U.S. National Assessment of the Consequences of Climate Variability and Change (the National Assessment). The National Assessment was organized by the agencies contributing to the U.S. Global Change Research Program (USGCRP) and the White House Office of Science and Technology Assessment. Appendix A provides a brief overview of the National Assessment.

The Pacific Assessment focused on the American Flag Pacific Islands, which include Hawai‘i, Guam, American Samoa and the Commonwealth of the Northern Mariana Islands, and the U.S.-affiliated Pacific Islands, which include the Federated States of Micronesia (Yap, Pohnpei, Kosrae and Chuuk), the Republic of the Marshall Islands, and the Republic of Palau. Engagement of scientists and decision-makers from throughout the Pacific Islands, and involvement of regional organizations like the East-West Center’s Pacific Islands Development Program (PIDP) and the South Pacific Regional Environment Programme (SPREP), helps ensure that:

- participants and sponsoring agencies understand the broad regional and international implications of addressing the challenges of climate variability and change;

**“Climate variability and change”** is used within this report to acknowledge two types of changes in the earth’s climate system.

**Climate “variability”** refers to relatively short-term variations in the natural climate system, such as the patterns associated with the ENSO cycle or the Pacific Decadal Oscillation (PDO).

**Climate “change”** is used in the IPCC context to refer to long-term changes— from decades to centuries— associated with increasing concentrations of greenhouse gases. Because variability and change both present significant challenges and opportunities to Pacific Island communities, both are addressed in this report.

## PACIFIC ISLANDS REGIONAL ASSESSMENT TIMELINE OF KEY EVENTS

March 1998 .....	Scoping Workshop “Consequences of Climate Variability and Change for the Hawai‘i-Pacific Region: Challenges and Opportunities,” held at the East-West Center in Honolulu, Hawai‘i
September 1998 .....	Proposal for initial Pacific Islands Regional Assessment submitted to USGCRP agencies
September 1999 .....	Project funding received through NSF Grant (OCE-9907547); partial funding had been forwarded by the NSF in June 1999 on behalf of the NSF, DOI and NOAA
Fall/Winter 1999 .....	Core scientific team begins initial analytical work and conducts initial discussions with key groups of stakeholders
March 2000 .....	First formal meeting of the Steering Committee for the Pacific Assessment
Spring/Summer 2000 .....	Analytical studies and stakeholder discussions continue
Summer 2000 .....	Working Group for the November 2000 Workshop established
November 2000 .....	Workshop “Climate and Island Coastal Communities” (Pacific & Caribbean) held at the East-West Center in Honolulu, Hawai‘i
Spring 2001 .....	Final Report of Pacific Assessment available for review and comment

- the Assessment targets problems and issues important to Pacific governments, businesses and communities;
- the Assessment benefits from expertise and insights from throughout the region; and,
- the results of this U.S.-funded activity are made available throughout the region.

The Pacific Assessment was coordinated by the East-West Center (in Honolulu, Hawai‘i) in collaboration with scientific partners from the University of Hawai‘i, the University of Guam and the National Oceanic and Atmospheric Administration (NOAA); in addition, it was closely coordinated with related activities supported under the auspices of the SPREP, particularly its Pacific Islands Climate Change Assistance Programme (PICCAP). Appendix B lists members of the core scientific team for the Assessment. Members of the team’s Steering Committee made substantial contributions of time and energy throughout the process— the Assessment would not have been possible without their commitment and the generosity of their home institutions. As will be discussed in more detail, the scientific team was comprised of close to 200 participants whose expertise and insights contributed to the findings and recommendations summarized in this report.

Financial support for the Pacific Assessment was provided by NOAA, the National Aeronautics and Space Administration (NASA), the U.S. Department of the Interior (DOI), and the National Science Foundation (NSF), with NSF serving

as the granting agency. Overall guidance for the Assessment was provided by a Steering Committee, which included representatives of businesses, national governments, resource managers and scientific institutions throughout the U.S.-affiliated Pacific Islands (see Appendix C).

### The March 1998 Workshop

The Pacific Assessment summarized in this report was a direct outcome of the March 1998 Workshop “Consequences of Climate Variability and Change for the Hawai‘i-Pacific Region: Challenges and Opportunities,” which was held at the East-West Center as part of the U.S. National Assessment effort.<sup>1</sup> As described in the workshop invitation, the week-long event was organized around two objectives:

- to initiate a long-term, interactive dialogue on the sensitivity of Pacific Island communities, businesses and ecosystems to climate variability and change; and,
- to explore opportunities to use new scientific information to adapt to or mitigate the consequences of climate variability and change.

Formal presentations at the beginning of the workshop provided participants with an opportunity to consider climate variability and change from three perspectives: a fundamental scientific understanding of the behavior of earth’s climate system; an awareness of the effects of climate

<sup>1</sup> Support for the March 1998 Workshop came from NOAA, DOI, NSF, NASA, and the U.S. Federal Emergency Management Agency.

variability and change on economic development, infrastructure and community planning; and, some insights into the vulnerability of unique Pacific Island ecosystems to climate variability and change. With these shared perspectives, workshop participants convened in smaller groups to begin a more in-depth exploration of the challenges and opportunities presented by climate variability and change in six key areas: fisheries; agriculture; water resources; community planning and economic development; biodiversity and endangered species; and public health and safety. Working-group reports were discussed in a closing plenary session that also addressed critical information needs and some overarching findings and recommendations. Appendix E provides a summary of the March 1998 Workshop.

That Workshop identified some underlying assumptions that were used to help guide the Pacific Assessment, including:

- climate variability and change are superimposed on, and should be addressed in the context of, other economic, social and environmental stresses;
- year-to-year climate variability (e.g., ENSO) and extreme events already pose significant challenges in the region, and it is essential to understand current patterns of variability and how they might change;
- today's problems should be addressed today, even as we plan for the future;
- the geographic size and isolation of island communities can create special circumstances—and conversely, island communities can be models for understanding and responding to climate variability and change;
- required data and information are often missing and/or inaccessible (e.g., there are gaps in critical monitoring programs, gaps in detailed research on local impacts, and a lack of attention to the direct impacts of climate change and the consequences of mitigation options);
- infrastructure and community support services are already stressed in a number of Pacific Island jurisdictions; and,
- there is a critical need to reduce the “information gap” between scientists and intended users of climate research and information—a task that involves addressing scientific, institutional and communication/education barriers.

## Conceptual Framework for the Pacific Islands Regional Assessment

### The Climate Context

The climate system is characterized by chemical and physical cycles and complex interactions between land, sea and air. The patterns that emerge from these interacting processes act on a variety of time and space scales. Spatially, ENSO is a phenomenon that occurs in the Pacific Ocean but has global manifestations. Conversely, global phenomena, such as the increase in atmospheric temperature associated with greenhouse warming, have powerful local implications. Throughout the earth's history, ice ages have repeatedly accompanied changes in earth orbit and solar activities. On shorter time scales, seasonal patterns and year-to-year variability, such as those associated with natural cycles like ENSO, are sustained within the climate system and punctuated by extreme events.

Historically, climate has been conceptualized as the statistical interpretation of precipitation and temperature data recorded over time for a given region. Observing atmospheric variations and discerning patterns remains key to predicting climatic conditions and extreme weather events. The scientific community has done a good job of this, as evidenced by our understanding of ENSO as a dominant pattern in the Pacific, and our recognition of other patterns such as the PDO. Similarly, science is showing how humans are affecting these patterns through increased emissions of greenhouse gasses. Recently, our understanding of climate has been greatly enhanced by dynamic integrated-systems approaches.

Understanding how the climate system works requires a study of bio-geo-physical processes. Understanding why climate matters requires a study of the interaction of climate with environmental and social systems at various time and space scales. Climate variability and change pose both challenges and opportunities for human communities that are simultaneously navigating changing demographic, economic, social and political conditions. Understanding how social systems respond to climate change and variability requires knowledge of how they are affected by those conditions today and how they might respond in the future if those conditions change. Historical analogs give us some insight into climate changes and corresponding social responses.

Climate, whether manifested as extreme events or persistent conditions, is experienced first as a physical phenomenon. Temperature, wind and rain all affect the biophysical environment; when extreme events such as tropical storms occur, people suffer injuries, habitats are destroyed (or enhanced) and the built environment is damaged. Climate is inextricably linked with hydrological processes and is a major factor in the process of soil formation. It sets the stage for the establishment of habitats, affects the pace of primary productivity, and influences species density and distribution. As one of the oldest of earth's systems, climate predates life on earth and sets the conditions in which terrestrial environments emerged. Ecosystems and communities evolve in the context of long-term trends, but they also are subject to extreme events that fall outside the norm. We are sensitive to the frequency, intensity and persistence of these conditions, as well as potential changes in long-term trends. Over the course of history, life on earth has evolved many remarkable adaptations to climate and climate variability, including reproductive, morphological and behavioral adjustments. In short, climate change and variability are expressed as environmental change and variability.

The physical environment is the material foundation for all human activities. Great amounts of time and energy are spent to convert the physical environment so that it provides subsistence—through development of water supplies, planting of crops, foraging for food, and construction of shelter. No matter how far some people may be from these physical activities, their survival continues to rely on the material world. Accordingly, any environmental change (induced by climate or other phenomena) introduces new opportunities or challenges for human communities. To better understand how climate change will affect these communities, it is important to consider how they rely on the natural and built physical environments, and how climate variability and change will affect these environments.

In recent years, concern over the consequences of climate change has led many to investigate the potential effects on human communities. Early appraisals focused on physical hazards alone, while more recent approaches, recognizing that human communities are at once physical and social, also have taken into account the social characteristics and organization of communities likely to experience dangerous conditions.

## Vulnerability to Climate Conditions

To date, interest in climate change has developed in the context of physical and biological impacts with limited exploration of social and economic effects. However, understanding what climate change and variability mean for ecological and social systems, and how we might respond, requires more than an understanding of basic processes and biophysical impacts. The application of vulnerability studies to the climate problem promises to enrich not only our understanding of social-climate interactions, but also our ability to respond to change and extreme events (see definition of “vulnerability” in the box below).

**Vulnerability** is described as a “multidimensional concept involving at least exposure—the degree to which a human group or ecosystem comes into contact with particular stresses; sensitivity—the degree to which an exposure unit is affected by exposure to any set of stresses; and resilience—the ability of the exposure unit to resist or recover from the damage associated with the convergence of multiple stresses.” (Clark et. al., 2000).

The Pacific Assessment team hoped to provide an opportunity for businesses, governments, community leaders, resource managers and scientists to explore the region's vulnerability in terms of impacts (a combination of sensitivity and exposure) and resilience (adaptive capacity). Thus, the approach adopted for the Assessment focused first on identifying how and why climate matters to Pacific Islands today, and then on exploring ways in which Pacific Island communities could reduce their vulnerability, either by reducing exposure or sensitivity, or enhancing resilience, or both.

The advantage of a focus on vulnerability is that, today and in the future, it can empower Pacific Island jurisdictions to consider a proactive rather than reactive approach to improving their ability to respond to climate variability and change. Historical experience and the results of model-based scenarios<sup>2</sup> of future climate were used to help stimulate the discussion, but the focus was on improving regional ability to anticipate and respond to changes in climate today and in the future. A vigorous and sustained commitment to support adaptation measures in Pacific Islands is particularly important in light of three key findings reported in the IPCC's Third Assessment Report:

<sup>2</sup> Consistent with guidelines for the National Assessment, participants in the Pacific Assessment were provided with a summary of climate change over the next 100 years based on the results of two coupled ocean-atmosphere models: the first generation coupled a general circulation model of the Canadian Center for Climate Modeling and Analysis (CGCM1) and a similar general circulation model used by the United Kingdom's Hadley Centre for Climate Prediction and Research (HADCM2). Both runs used the core scenario for the National Assessment, which is a 1% rate of annual increase in carbon dioxide and sulfate aerosols (the GHG+A scenario).

- human influences will continue to change atmospheric composition throughout the 21st century;
- global average temperature and sea level are projected to rise under all scenarios in the IPCC Special Report on Emissions Scenarios (SRES); and,
- anthropogenic climate change will persist for many centuries (IPCC, 2001).

## The Pacific Assessment— Objectives and Approach

Reflecting discussions about the National Assessment at the 1997 Aspen Summer Institute, and building on insights that emerged from the March 1998 Workshop, the Pacific Assessment sought to achieve two, mutually-supportive objectives:

- development of a more complete understanding of the regional consequences of climate variability for Pacific Island jurisdictions, considering economic, social and other environmental stresses; and,
- support for a dialogue among scientists, governments, businesses and communities in the Pacific Region that promotes the use of climate information to support decision-making.

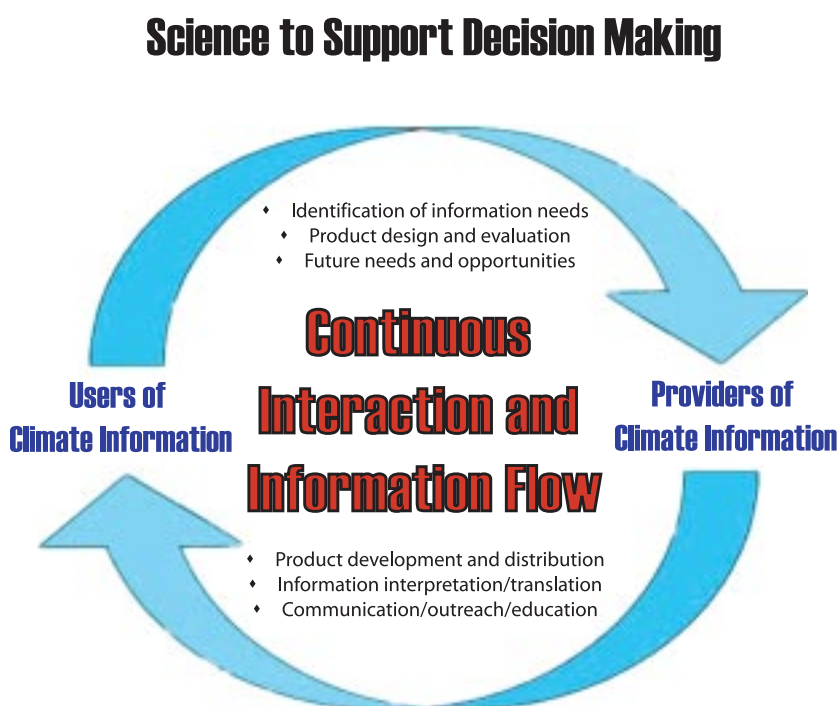
This dialogue will allow diverse stakeholders to develop a shared understanding of climate effects and possible responses, and to use climate information to support

decision-making. This concept of shared learning and joint problem-solving emerged as a defining characteristic of the Assessment and reflects an evolving paradigm of assessments as a process of dialogue among scientists and stakeholders.

Thus, the Pacific Assessment can be viewed as a component of broader efforts to develop and use climate information to support decision-making (see Figure 1 below).

The programmatic backbone of the Assessment, and the central process animating this new regional climate information system, is the work of sustaining the partnerships necessary to produce, communicate and use new information and shared insights into climate variability. Pursuant to recommendations from the March 1998 Workshop, the Assessment team has given highest priority to exploring the implications of climate variability and change for:

- water resources (e.g., droughts associated with the El Niño, and potential changes in rainfall patterns associated with long-term climate change);
- public health and safety in island coastal communities; and
- economic development and resource management in key sectors such as tourism, agriculture, and marine and coastal resources, especially as these are affected by changes in patterns of extreme events such as hurricanes and typhoons.



*Figure 1.  
Conceptual model of a Pacific Climate  
Information System (PCIS), which incorporates  
science and broad-based collaboration into  
public decision-making.*



Although the Assessment focused primarily on the direct consequences of climate variability and change within Pacific Island communities, the organizers and participants acknowledged the importance of recognizing that the effects of climate variability and change on other jurisdictions in the Asia-Pacific Region (and throughout the world) also have environmental and economic implications for Pacific Islands.

The Assessment supported analytical studies, a large, multi-stakeholder workshop and focused discussions with representatives of key sectors. The studies helped illuminate the nature and consequences of historic and projected climate trends, and included analysis of model-based scenarios of climate change over the next 50 and 100 years. The November 2000 Workshop focused on the role of climate in island coastal communities. Focused, small-group discussions included consideration of climate variability and change issues by: representatives of the Pacific Basin Coastal Zone Management officials at their 16th Annual Conference in January 1999; the Hawai'i Congress of Planning Officials at their September 1999 Conference; participants in a fall 1999 workshop on ENSO and water resources held in Fiji under the auspices of PEAC and SOPAC; and participants in a workshop on climate and health held in Samoa in 2000 under the joint auspices of the World Health Organization (WHO) and the World Meteorological Organization (WMO).

Participants in the Pacific Assessment were asked to consider vulnerability in the context of two questions:

- What systems, activities, communities and populations are particularly exposed and sensitive to climate, and how? and,
- How might we enhance the adaptive capacity of these systems, activities, communities and populations?

To further enhance adaptive capacity, particularly in light of recent developments in science and decision-making, participants were asked to think strategically about the following:

- What information/research is needed to reduce sensitivity or enhance adaptive capacity (build resilience)?
- How can information about climate be used to enhance planning, policy formulation and decision-making?
- What cooperative partnerships could be pursued to enhance adaptive capacity?

The insights that emerged from the Assessment dialogue on these five questions provide the basis for this report.

## Organization of this Report

This report provides an integrated summary of the scientific analyses conducted as part of the Pacific Assessment, and the insights that emerged from the March 1998 and November 2000 Workshops and small-group discussions.

The report was reviewed and approved by the Pacific Assessment Steering Committee, and participants in both Workshops were invited to comment on the draft report. In addition, the draft was made available for public review and comment via posting on the East-West Center climate website ([www2.eastwestcenter.org/climate/assessment](http://www2.eastwestcenter.org/climate/assessment)). A detailed summary of the comments received and addressed during review of this report is available from Principal Investigator Eileen L. Shea, Climate Project Coordinator at the East-West Center.

Subsequent chapters of this report will provide:

- A description of the Pacific Islands region, including an overview of regional climate and socioeconomic conditions and a summary of the results of the model-based scenarios of climate change (Chapter Two);
- A discussion of climate-related challenges and opportunities faced by Pacific Island communities, focusing on vulnerability in the six key sectors used to organize the November 2000 Workshop (Chapter Three); and,
- A discussion of planning for the 21st Century, with emphasis on development of effective response options; identification of critical information gaps and research needs; support for critical regional partnerships that use climate information in decision-making; and a concluding discussion of future activities (Chapter Four).

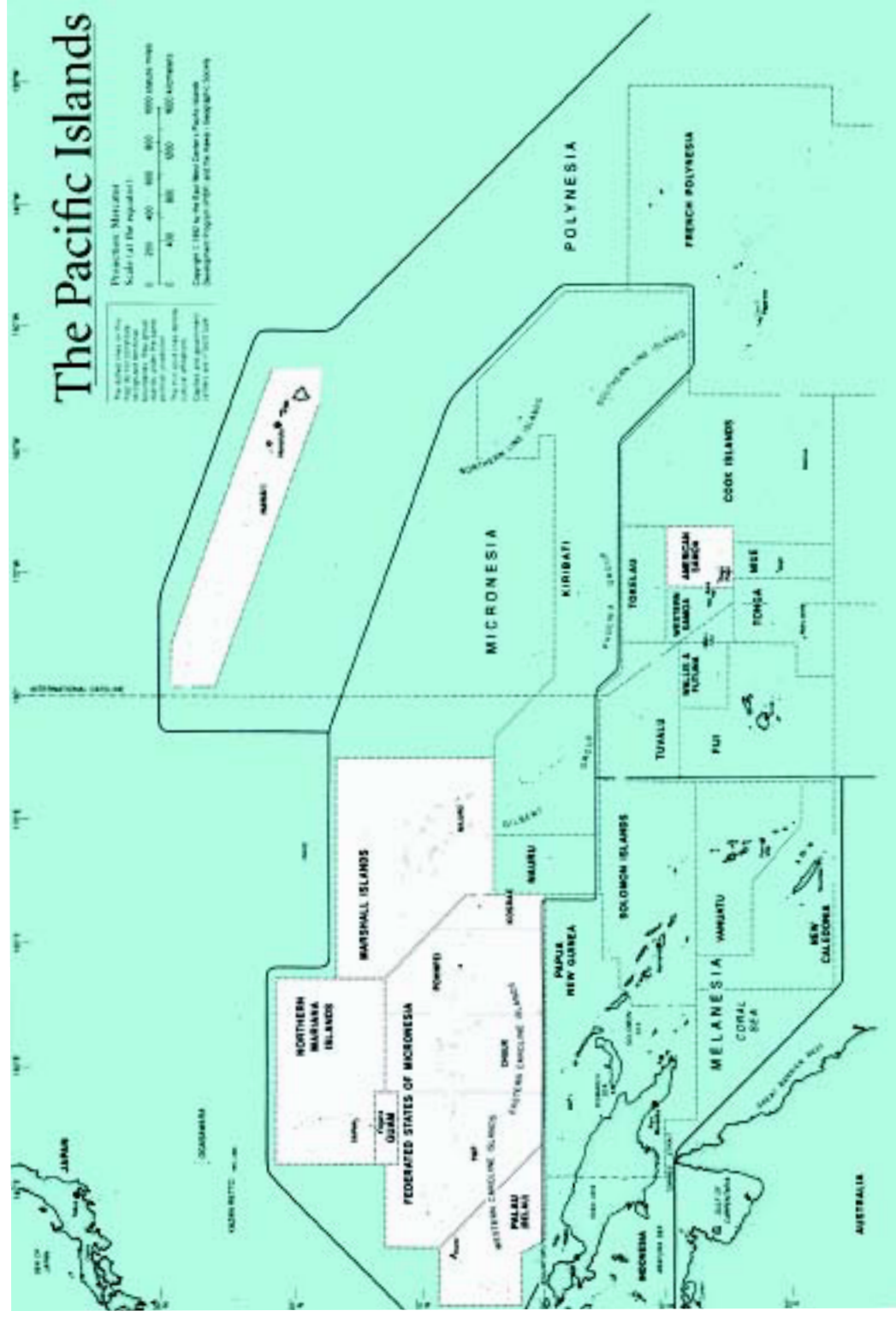
Additional details on the Assessment process are contained in the following appendices:

- An overview of the U.S. National Assessment (Appendix A);
- Key members of the Pacific Assessment core scientific team (Appendix B);
- Members of the Steering Committee for the Pacific Assessment (Appendix C);
- Selected materials related to the November 2000 Workshop on Climate and Island Coastal Communities, including the Workshop Summary, Workshop Agenda, Members of the Steering Committee, List of Working Group Chairs and Rapporteurs, and List of Participants (Appendix D);
- Selected materials related to the March 1998 "Workshop on the Consequences of Climate Variability and Change for the Hawai'i-Pacific Region: Challenges and

Opportunities” including the Workshop Summary, Members of the Steering Committee, List of Working Group Chairs and Rapporteurs, and List of Participants (Appendix E); and

- A proclamation issued by the governor of Hawai‘i on the occasion of the March 1998 Workshop (Appendix F);

Rather than an end product, this report represents the beginning of a sustained process of dialogue and information-exchange among scientists, businesses, governments and communities in the Pacific Region. It is our hope that this report will serve as a guidepost for those seeking to better understand current and future climate-society interactions in the region, and will also inspire people from all walks of life to explore together how climate affects our lives.



Shown in the white areas of this map, the American Flag and U.S. Affiliated Pacific Islands (AFIUSAD) are the principal participants in the Pacific regional climate assessment, which supports collaborative research and planning to mitigate the negative effects of climate variability and change.



# CHAPTER TWO—PACIFIC ISLANDS REGION

## Defining the Region

If you were to draw together all 58 million square miles of the Earth's land area and place it in the Pacific Basin, that land would still be an island in the middle of a great sea—the Pacific Ocean is vast. However, while some may view the sea as a barrier, for many others it is a highway. Historical trade routes and settlement patterns throughout the Pacific produced strong cultural links among the 30,000 Pacific Islands, and have resulted in distinctive Polynesian, Melanesian, and Micronesian spheres of influence. Later, colonial and post-colonial histories resulted in political alignments that crossed cultural boundaries. This exploration of climate change focuses on the Pacific Islands that are politically affiliated with the United States.

As inhabitants of small island states, the people of the Pacific share certain vulnerabilities to climate change and variability. Similarities include the processes of soil and coastal zone formation, susceptibility to ocean-born storm systems and tidal fluctuations, hydrology, biogeography (including population density, species density and distribution), and limited resource bases. Differences derive from variations in island geology such as history of formation (continental islands versus volcanic islands); relative size, isolation and age (from high island to atoll); extent and nature of reef formation; and the capacity of natural aquifers.

The economic strategies of each community reveal something of the relationship between island peoples and the physical elements of their islands. While human emotion and spirit can be affected by climate change and variability, it is the physical and material dimensions of the human experience that make us most vulnerable. Moreover, physical vulnerability is inextricably linked with social systems. These systems at local, island, regional and even international levels influence not only human exposure to climate change and variability, but also human adaptive capacities. The values and beliefs that underpin economic decisions—and the social structures that distribute opportunities and constraints—are all culturally informed. In sum, willingness to adapt, resilience to change, knowledge of climate systems, and trust in policy makers and partners all affect the vulnerability of island populations.

## Describing the Region: Islands and Coastal Communities

### *Island Geography and Geology*

American flag and U.S.-affiliated Pacific Islands (AF/USAPI) include the Hawaiian islands; the Samoan islands of Tutuila, Manua, Rose, and Swain; and islands in the Micronesian archipelagos of the Carolines, Marshalls, and Marianas. The Micronesian islands include the territory of Guam, the Commonwealth of the Northern Mariana Islands (CNMI), the Freely Associated States of the Republic of Palau (Palau), the Republic of the Marshall Islands (RMI), and the Federated States of Micronesia (FSM)—all north of the equator in the western Pacific. The Hawaiian islands lay further to the east, and American Samoa is the only AF/USAPI south of the equator.

Geomorphically, these islands are exceedingly varied and therefore difficult to generalize. The AF/USAPI include volcanic islands, continental islands, atolls, limestone islands, and islands of mixed geologic type. About half of the Caroline Islands and 80% of the Marshall Islands are atolls, some of which peak at only a few feet above present sea level. Volcanic islands, on the other hand, can reach heights of more than 13,000 feet, as does the snow-capped peak of Mauna Kea on the island of Hawai'i.

Island landforms, however, are not solely the product of geological histories. In the Pacific, climatic and oceanographic controls are important causes of landform variation as well (Nunn 1999). Changes in rainfall and the water-table level are especially important in this regard and have been implicated in such fundamental processes as bedrock formation (Schmalz 1971), the development of the amphitheater-headed valleys commonly found in the Hawaiian Islands (Nunn 1994), and the development of phosphate rock (Stoddard and Scoffin 1983).

The combined affect of geologic, oceanographic, and climatological processes can have profound effects on the peoples who settle these islands. High volcanic islands, which tend to have larger surface areas, generally have more fresh water, better soils, and more diverse resource bases. Low-lying atolls, on the other hand, are especially prone to drought and erosion, and generally (at least on land) have limited natural resources. Finally, the interaction of climate and sea dramatically affects coastal zone formation and will continue to do so as sea levels rise.

### *Island Ecosystems*

As might be imagined by the diversity of island forms, Pacific Island landscapes and biodiversity are many and varied as well. Warm temperatures and moisture have supported the growth of tropical forests on many islands, particularly the high islands. Forested areas are still common in upland areas of Hawai'i and American Samoa, Pohnpei, and Kosrae.

While even relatively small islands can host a diversity of forest types, atolls generally do not support dense forest vegetation in part because of the soil composition and hydrological constraints. These relatively small islands are coastal zones. Boundaries between land and sea fluctuate throughout the year. Mangrove forests fringe some islands, in zones where salt water and fresh water mix to form the breeding grounds for many valuable fish species. Rich lagoons interlace other islands, bountiful with fish and other marine life. Throughout the region, coral reefs are abundant and productive, attracting myriad fish species that in turn attract subsistence and commercial fishermen.

Though these Pacific ecosystems differ from each other in many important respects, they are all islands, and much of the condition and vulnerability of their biota derives from that fundamental characteristic. Oceanic islands have lower overall levels of biological diversity. Island species are much more likely to be endemic (found only on a single island or archipelago) and to occupy restricted habitats. Islands generally are more susceptible to disruption by biological invasions. The combination of land-use change, human-driven species introductions and certain unique characteristics of islands has made island species and ecosystems more vulnerable than their continental equivalents to human endangerment and destruction.

There are a number of conditions that affect most island ecosystems and their biological resources. The extinction of

species and genetically distinct populations is an irreversible component of human-caused global change, and to date extinction has been disproportionately significant on islands. Any list of threatened or endangered species reveals that islands remain enormously vulnerable to future losses. The Hawaiian Islands, for example, make up only about 0.002% of the United States' land area, but are the sole home for nearly 30% of the nation's endangered species. Furthermore, biological invasions by human-transported alien species are a major driver of endangerment and extinction, and a significant element of change in their own right. The extent of biological invasion on islands generally is much greater than in continental systems, and, overall, constitutes the major ongoing threat to the unique biodiversity of islands.

Another feature that all of the islands in the Pacific Region share is a dependence on coral reefs, which in addition to hosting a wealth of marine life also provide a natural form of coastal protection against wave and wind damage. In addition to the many human-induced stresses, reefs are sensitive to temperature increases—as evidenced by significant coral bleaching associated with the 1997–1998 El Niño—as well as to the damaging effects of hurricanes and tropical cyclones. Finally, island ecosystems are affected by human population growth, economic strategies and governance systems.

### *Island People*

The AF/USAPI are home to an estimated 1.7 million people, though the distribution of people throughout the islands is highly imbalanced (see Table 2.2). Consider that 1.2 million live in the state of Hawai'i, while the Republic of Palau is home to fewer than 19,000. This disparity is indicative of the range of diversity in human settlement in the region, as well as the range of challenges and opportunities facing communities in each island jurisdiction.

Similarly, population growth rates vary widely throughout the islands. The population of RMI, FSM, and Guam are all expected to double within the next 31 years, while the Republic of Palau will not double until 2068 (based on a natural rate of increase: Population Reference Bureau, 2000). These figures compare with an estimated doubling time of 51 years for global population. The high natural rate of increase in many AF/USAPI is accentuated by high migration rates. The distribution of populations within and between island groups can have dramatic implications for climate-society interactions. Consider, for instance, that in the Marshall Islands, 65% of the population is urban, while in the FSM only 27% is urban. The spatial distribution of human populations has clear implications for water



*Hawaiian Green Sea Turtles are among the endangered species in Pacific ecosystems that are affected by climate change and other natural factors.*

## FOCUS: CLIMATE AND BIODIVERSITY

Climate variability—the ENSO cycle, decadal variations, and extreme events such as hurricanes and other major storms—has always influenced Pacific organisms and cultures. However, the consequences of climate variability for biodiversity have changed in recent years, for two primary reasons. First, many native species are now present only as small, often fragmented populations, frequently persisting only in marginal portions of their former range. These marginal environments may be particularly vulnerable to climate variability. For example, introduced mosquitoes and the avian malaria they transmit continue to plague Hawaiian honeycreepers, endemic species that have been crowded into high-elevation forests on the upper edge of their former range due to habitat destruction by humans and other introduced species, including birds and ungulates. ENSO-related drought conditions can be significant in these higher sites where the honeycreepers are now found.

A second reason why the effects of climate variability have changed is that introduced species are now widespread on most Pacific Islands, and disturbances such as hurricanes and other large storms generally further facilitate the establishment of those species. In the case of Hurricane Iniki on Kaua'i, introduced species responded aggressively to fill the void left by the damage to native forests.

Climate change, therefore, has direct effects on Pacific Island species and ecosystems, and it is very likely that its effects are multiplied through interaction with land-use change, over-harvesting, species invasions and other aspects of human-caused changes in biodiversity. Components of climate change that affect biodiversity in Pacific Islands include:

- sea-level rise, which can jeopardize habitats and affect the availability of fresh-water resources, particularly on atolls and low islands;
- increasing temperatures, which can affect the viability of species (e.g., some corals are susceptible to small increases in temperature and may be unable to recover from bleaching if ocean temperatures exceed their optimal range);
- changes in rainfall, which can affect species and ecosystems directly through impacts on the availability of fresh-water resources; and,

- increasing carbon dioxide (CO<sub>2</sub>) levels, which for some systems may have a greater effect than changes in temperature and precipitation.

Changes in CO<sub>2</sub> levels affect the growth, chemistry and efficiency of water use for native and introduced species, and these changes in turn affect the distribution of ecosystems and the palatability of plants as food for animals. For example, changes in growth rate may provide an advantage to some weedy, introduced species, while change in the distribution of ecosystems presents an opportunity for other introduced species. In marine ecosystems, there is evidence that skeleton-building by corals (calcification) can be reduced by elevated CO<sub>2</sub> levels, which, when combined with increasing temperatures, could represent a double stress for corals.

Finally, there is the possibility for “surprise” changes in the climate system that may occur abruptly rather than being manifested as gradual changes in trends or mean conditions.

Many of the strategies that Pacific Island communities could implement to reduce the vulnerability of species and ecosystems to climate variability and change involve reducing current human-related stresses on those species and ecosystems. Reducing these stresses is essential for building resilience to future climate changes. Some specific activities could include:

- Strengthening land-use policies and enforcing existing policies, which could make a substantial contribution to protecting terrestrial habitats and marine ecosystems from sedimentation and nutrient pollution;
- expanding education and public awareness programs, which can improve our understanding of the economic and cultural value of biological diversity, and enhance development of a sustained commitment to effective stewardship; and,
- developing more effective partnerships among scientists, government agencies, resource managers, businesses, and local communities, which could significantly enhance efforts to understand and respond to the consequences of climate variability and change on biodiversity and, more broadly, on Pacific Island communities.

management systems that are highly sensitive to climate change and variability. Furthermore, urban poor are, in general, notoriously vulnerable and least able to adapt to extreme events, so rural to urban migration, if not coupled with careful planning and infrastructure development, can increase overall sensitivity to climate change while reducing adaptive capacity. Conversely, migration in some instances is an adaptive strategy. The money sent to the islands from

workers overseas (remittances) for instance, can help to alleviate domestic vulnerability by strengthening economic vitality.

### *Pacific Island Economies:*

In small-island states, natural resources are generally limited. Geographic remoteness is typical, and the associated costs of transport and shipping have a profound

influence on island economies. National, territorial or statewide economic profiles reflect a common bundle of strategies, though relative emphasis varies from island to island (see Table 2.1). Tourism, for instance, figures prominently in the gross domestic product of most island jurisdictions. It has been the largest source of income in the Republic of Palau (Osman, 2000), while in Hawai'i the travel and tourism industry produced an estimated \$6.3 billion in 1998, second only to real estate in terms of its contribution to the state's GDP (World Travel and Tourism Council Hawai'i Tourism Report, 1999). Considerable tourism infrastructure has been developed in Hawai'i, Guam, and CNMI, though the prominence of tourism in CNMI's economy has dwindled since 1997 (Osman, 1999b). On the other hand, traffic to the Marshall Islands and American Samoa is more

<b>Region/ country or territory</b>	<b>GDP (US\$ in millions)</b>	<b>Per capita GDP (US\$ in thousands)</b>	<b>Major income sources</b>	<b>Major Sources of External Investment</b>	<b>Major Future sources of Income</b>
<b>FSM</b>	230.0	1,977	¥ U.S. payments ¥ Government services ¥ Fisheries ¥ Tourism	U.S., Japan	¥ Compact status being renegotiated ¥ Fisheries development
<b>Guam</b>	3,065.8	18,766	¥ Tourism ¥ Military ¥ Trade ¥ Services	U.S., Japan, Korea	¥ Tourism ¥ Services
<b>RMI</b>	102.1	2,009	¥ U.S. payments ¥ Kwajalein Missile Range ¥ Government services ¥ Copra ¥ Fisheries	U.S., Japan	¥ U.S. military compact being renegotiated ¥ Fisheries
<b>CNMI</b>	664.6	8,367	¥ Tourism ¥ Garment manufacturing ¥ Trade ¥ Services	Japan, Korea, Hong Kong, U.S.	¥ Tourism ¥ Services
<b>Palau</b>	129.3	6,989	¥ U.S. Compact Payments ¥ Tourism	Japan, U.S.	¥ Compact money ¥ Tourism
<b>American Samoa</b>	253.0	4,295	¥ Tuna Canning ¥ Government Services ¥ Remittances from Samoans overseas.	U.S.	¥ Canneries ¥ Remittances ¥ U.S. entitlements
<b>Hawai'i</b>	35,146.4	29,164	¥ Tourism ¥ Services ¥ Trade ¥ Government	U.S., Japan, Australia	¥ Tourism ¥ Defense services ¥ Trade ¥ Government

*Source: Osman, W. Pacific Island Fact Sheet. Bank of Hawai'i Economic Reports, 2001*



*Waikiki, Hawai'i is a premiere global destination for tourism, which comprises a varying but substantial proportion of all economic activity in the Pacific Islands.*

oriented to returning residents than to vacationing tourists.

Another component of economies throughout the AF/USAPI, particularly in the freely associated states (Palau, FSM and the Republic of Marshall Islands), is the significant role of government spending. Compact payments for exclusive access to island waterways and military rents have buttressed the public sector and, in several jurisdictions, have been the primary source of revenue for recipient governments. By contrast, the private sector plays a key role in other jurisdictions, notably Hawai'i, Guam, and CNMI. In Guam, private sector employment replaced government as the largest employer for the first time in 1998 (Osman, 1999a). In CNMI, lax labor and immigration laws and access to U.S. markets have hastened the development of garment



## THE EFFECTS OF MIGRATION

Migration (both within and across international borders) is one of the most important processes affecting both the structure of Pacific Island populations and the growth and distribution of Pacific Island workforces. Migration patterns are shaped, at least in part, by differential resource bases, historical geopolitical relations, and vulnerability to climate-related extreme events such as hurricanes, typhoons, cyclones, and drought.

Prior to FSM's independence, internal migration trends revealed a movement of people from outlying islands to administrative centers (Sudo 1997), in part because urban centers held the promise of education, medical care, and income (Appleyard 1988). This movement, though, also includes climate refugees who flee drought-stricken or typhoon-ravaged islands and atolls; it is a movement away from places that are perceived as personally dangerous, or conditions that are difficult (Pirie 1994).

**Net Migration Rate in American Flag and U.S.-affiliated Pacific Islands (2000 estimates)**

Country or territory	Net migration rate
FSM	11.65 migrant(s)/1,000 population
Guam	5.35 migrant(s)/1,000 population
RMI	0 migrant(s)/1,000 population
CNMI	19.06 migrant(s)/1,000 population
Palau	5.01 migrant(s)/1,000 population
American Samoa	3.74 migrant(s)/1,000 population

*Source: CIA World Factbook*

While substantial migration from Guam and American Samoa began after WWII, a wave of Micronesian migrations followed independence of the trust territories. Hawai'i, Guam and CNMI in particular have attracted many migrants from other islands' jurisdictions; so many, in fact, that Guam and CNMI have asked the federal government for repayment of expenses linked to Micronesian migrants granted access to U.S. territories by virtue of the compact of free association (Osman 2000).

Many islanders moved to urban centers abroad as well. In 1990, 62.4% of American Samoans lived abroad. Roughly 30% of Palauan nationals have emigrated to live in foreign countries; at the same time, Palau has accepted the same number of Philippine and Chinese laborers (Sudo 1997). Like Palau, other AF/USAPI have attracted migrants from throughout Asia and the Pacific. CNMI, for instance, has experienced a net in-migration flow (Rappaport 1999) largely due to the emergence of the garment and manufacturing industry.

The bottom line is that migration, both internal and international, is a key factor in determining the distribution and density of communities, and can have a profound effect on climate/society interactions in the AF/USAPI.

manufacturing, which grew from 13% of CNMI's gross business receipts (in 1990) to 29.3% (in 1998) (Osman, 1999b). In Hawai'i, financial services and digital technology are beginning to play a substantial role in the state's changing economy.

Where island resource bases are limited, marine resources are often extensive. Exclusive Economic Zones (EEZ), which extend up to 200 miles out from each jurisdiction, offer a source of income to many islands through sale of fishing rights to U.S., Japanese, Taiwanese, Korean, and other fishing fleets. American Samoa is the only AF/USAPI to have invested substantially in the value-added tuna canning industry, but tuna trans-shipment has been an important small industry in Guam and has provided some employment in Palau. Estimates of expenditure on fuel, provisions, and services by tuna fleets on Guam have been as high \$118 million per year.

In general, commercial agriculture in the AF/USAPI serves domestic markets, though export-oriented plantation agriculture was once the foundation of Hawai'i's economy. Commercial agriculture also played a major role in Micronesia during the Japanese occupation. In the RMI, copra production has been and continues to be an important source of income. Subsistence and semi-subsistence agriculture, on the other hand, are major components of many local economic strategies.

### *Social systems*

Migration and settlement have infused the region with considerable social and cultural diversity. Monsoon winds propelled early migrants (about 4,000–5,000 years ago) from the Philippines and Indonesia all around the Pacific Basin. The first settlers arrived in Palau and Yap, then continued north to Guam and through the Northern Marianas. The Caroline and Marshall archipelagoes were probably settled by peoples from the Solomon Islands or Vanuatu (Kirch, 2000). Today, there are seventeen languages spoken in the FSM alone, including two Polynesian dialects, fourteen Micronesian languages, and English. Polynesian migration patterns are characterized by fantastic voyages. Using only the stars and stories, early settlers journeyed thousands of miles across open ocean to reach the most geographically remote islands in the world— Hawai'i. While it is difficult to generalize about traditional society in a region as vast as this, some commonalities are evident. The importance of clans and lineages in local social organization, the prominent role of chiefs, and the close cultural, economic and spiritual relationship with land



## SUBSISTENCE PRACTICES

Island economies employ a range of strategies to secure and sustain the welfare of their communities. At the household level, island livelihoods include a combination of subsistence farming and fishing, salaried or wage labor, and entrepreneurial ventures—though relative emphasis on each of these economic strategies varies widely among the jurisdictions. Hawai'i, Guam and CNMI, for instance, have well-developed cash economies, strong links with international markets, and service sectors that play key roles in their economies. To illustrate, revenues from services accounted for 18.1% of CNMI's gross business revenues in 1998 (Osman 1999b). In other jurisdictions such as FSM and American Samoa, nonmarket production is the cornerstone of local economies. Nonmarket production includes subsistence activities and production for nonmonetary trade, both of which figure prominently in island economies but are not fully represented in official figures.

Traditional agriculture, though still practiced, has changed considerably. Changing patterns of land tenure, new consumer preferences, and changing conditions in wider society have altered land-use practices in many of the AF/USAPI. While few livelihoods rely exclusively on subsistence activities, nonmarket fishing, cultivation, and animal husbandry continue to play a significant role in local and, hence, island-wide

economies. As these activities are most closely associated with the physical environment, they are the most sensitive to climate change and variability.

Subsistence fishing is still an important food source for most island communities. The FAO estimates that worldwide average annual consumption of fish is 13 kg per capita; however, average consumption in Palau exceeds 100 kg per capita (Lal and Fortune, 2000). In all the Pacific Islands (except Tonga) subsistence catches far outweigh the commercial harvest, including for tuna (Lal and Fortune, 2000).

Despite changing preferences and availability of imported foods, subsistence agriculture continues to play a major role in the AF/USAPI. Consider that of the 1,126 farms in American Samoa in 1990, 88% produced solely for subsistence (Osman, 1997). Indigenous cultivation systems incorporate a range of land uses including home gardens, shifting cultivation and agroforestry (tree crops such as coconuts, breadfruit, and bananas). In Yap, as much as 27% of the vegetation may be classified as agroforest (Falanruw, 1994). Cultivation of wetland taro still plays a significant role in the lives and livelihoods of many islanders, particularly in the FSM, where it is the staple crop. Wetland taro is very sensitive to changes in precipitation and saltwater intrusion.

and sea, for instance, are all characteristic of pre-contact social systems.

Contact with Europeans began with Magellan's fleet. His was the first recorded circumnavigation of the globe and included a landing in Guam in 1521. Not long after, the Spaniards arrived and claimed the islands for the Crown. Soon after, soldiers appeared in Guam, Saipan, and Palau. Catholic missionaries followed. During this period, many of Guam's indigenous Chamorro communities were relocated. German, English, and Russian whaling expeditions began frequenting the area in the early 19th century, and new patterns of migration emerged at the turn of the 20th century. Germans purchased many islands from the Spanish, and American soldiers in the wake of the Spanish American War later claimed the islands that had not been sold. Japanese forces began to arrive in 1914 and asserted jurisdiction over the German land claims. Japanese influence and migration to the region continued through World War II (Hezel 1995).

After World War II, the United States by U.N. Mandate established a "Strategic Trust" relationship with what is now the RMI, the FSM, the Republic of Palau, and the CNMI. American military personnel and administrators established themselves throughout the region and brought with them American social and cultural institutions.

Contemporary social systems throughout the AF/USAPI vary widely; they are a mix of traditional Micronesian or Polynesian rules and institutions as well as those adopted from colonial or industrialized countries. In some sense Hawai'i and Guam stand at one end of the spectrum of economic development and westernization. At the other end are the FSM and American Samoa. In Hawai'i and Guam, cash economies are highly developed and highly dependent on tourism, and very few people rely on



*Subsistence fishing supports much of the rural population in many Pacific islands, yet is particularly susceptible to climate-induced changes in coastal ecosystems (photo by Joseph Konno).*

**Table 2.2: Comparison of Regional Populations**

Region/ country or territory	Last census	Population at last census	Mid-year population estimate 2000	Mid-year population estimate 2010	Land area (km <sup>2</sup> )	Population density (people/ km <sup>2</sup> ) circa 2000	Projected annual population growth rate (%) circa 2000	Projected population doubling time (in years)
<b>FSM</b>	1994	105,506	118,100	141,900	701	168	1.9	36
<b>Guam</b>	1990	133,152	148,200	171,700	541	274	1.0	66
<b>RMI</b>	1999	50,840	51,800	63,200	181	286	2.0	35
<b>CNMI</b>	1995	58,846	76,700	90,700	471	163	5.5	13
<b>Palau</b>	1995	17,225	19,100	23,000	488	39	2.2	32
<b>American Samoa</b>	1990	46,773	64,100	80,300	200	321	2.9	24
<b>Hawai‘i</b>	2000	1,211,537	1,211,537	1,440,000	16,636.5	72.8	0.7	NA

*Source: Secretariat for the Pacific Community, Oceania Demographics—except for Hawai‘i data, which derives from the U.S. Census 2000, the State of Hawai‘i Databook 1999, and the Population Reference Bureau.*

subsistence gardening or fishing. In American Samoa and the FSM, traditional political structures are still in place and people outside the urban centers rely heavily on fishing and gardening for their food. In Guam and Hawai‘i, western legal systems dominate, whereas in American Samoa and the FSM, traditional norms continue to govern behavior in rural areas.

Chiefly systems persist throughout the islands, and have retained an especially influential role in planning and decision-making in the RMI, parts of the FSM, and American Samoa. Environmental management in the islands, to be effective, relies on collaboration between these various decision-making authorities, each of which brings something unique to the process. Local and national decision-making and planning organizations are augmented by grassroots, regional, and international organizations. These organizations and institutional arrangements, if constructively engaged, can enhance the adaptive capacity and reduce the sensitivity of island coastal communities to climate change and variability. Such cooperation could be through the sharing of knowledge, experience and information about climate conditions and the effects of climate on environmental and social systems.

## Today’s Climate

In spite of fundamental physical similarities, the range of variation within the Pacific Islands is extraordinarily broad.

The islands differ geomorphologically, from atolls with small, low islets and extensive lagoons, to raised limestone islands, to volcanic high islands with substantial topographic and internal climatic diversity (microclimates). They differ climatically as well, from wet western equatorial islands to seasonal tradewind environments—and they differ in their exposure and sensitivity to cyclones and to ENSO-related climatic variability. The following brief summaries highlight the prevailing climatic conditions in the jurisdictions addressed in this Report. Most of the material in this section is excerpted from reports on the individual jurisdictions contributed to the Pacific Meteorological Needs Analysis Project (PMNAP) conducted by the South Pacific Regional Environment Programme (SPREP, 2000).

### *American Samoa*

American Samoa has a tropical maritime climate with abundant rain and warm, humid days and nights. Annual rainfall, usually in the form of showers, averages about 125 inches a year at the airport, but varies greatly over small distances because of topography. For example, Pago Pago, less than 4 miles north of the airport, at the head of a hill-encircled harbor open to the prevailing wind, receives nearly 200 inches a year. The crest of the range receives substantially more than 250 inches. The driest months are June through September (winter in the southern hemisphere, where American Samoa is located) and the wettest are December through March (summer in the southern hemisphere). Heavy showers and long rainy periods can occur in any month. Flooding rains are not unknown and

some of these are associated with tropical cyclones that usually only affect American Samoa during El Niño periods. The prevailing winds throughout the year are easterly trades, interrupted more often in summer than winter, and sometimes associated with tropical cyclones, convergence bands, and upper level disturbances.

#### *Commonwealth of the Northern Mariana Islands*

Climatologically, the Mariana Islands are considered the sunniest islands in Micronesia. Rainfall is concentrated in July, August and September. Northeast tradewinds dominate from November to March with easterly winds predominant from May to October. Typhoon season runs from July to January, and the islands of the CNMI are usually subject to at least one typhoon each year.

Saipan is the largest island in the CNMI and the second largest of the Mariana Islands (Guam is the largest). Saipan is the most populated island and is the seat of government as well as the site of most economic activity in the CNMI. The west coast of Saipan is protected by a fringing barrier reef, while the relative absence of reefs on the east make that side of the island subject to strong waves fed by the tradewinds, particularly during Saipan's winter (November to April).

Average year-round temperature is 84° F with an average humidity of 79%. The ocean temperature averages 82° F. Occasional passing rain showers and gentle prevailing northeast tradewinds provide an environment that has been described as, "as perfect as it gets."

#### *Federated States of Micronesia*

The following paragraphs provide brief summaries for each of the individual states that comprise the FSM.

**Kosrae**— Kosrae is the only FSM state without outer islands, and is the most easterly state in the country. It has the smallest land area (only 42 square miles, or 112 square kilometers) and consists of two islands joined by a causeway. Kosrae's climate is tropical oceanic, and heavy rainfall has created numerous perennial streams. The average annual temperature is 81° F and average annual rainfall is 175.9 inches (4466 mm). Located only 5° north of the equator, Kosrae experiences periods of heavy rainfall associated with the Intertropical Convergence Zone (ITCZ). Most tropical storms pass north of the state, but the effects of typhoons can be felt in the area.

**Pohnpei**— Kolonia, capital of the island state of Pohnpei, receives roughly 16 feet (192 inches) of annual rainfall, with twice that amount falling on the interior mountains. Annual rainfall at the weather observatory is 193.6 inches,



*The 1997–98 El Niño drought had a devastating effect on taro, an important subsistence crop in many Pacific islands, including the Federated States of Micronesia (photo by Joseph Konno).*

and average annual temperature is 80° F. The island's highest point, at 2540 feet (798 meters), is the summit of Mount Nahnalaud, thought to be one of the wettest spots in the world, with an average annual rainfall exceeding 400 inches. Pohnpei is a large state, with most of its islands and atolls in the north-central, southwest, and western parts of the state. The northern part of Pohnpei is where tropical disturbances often form, though most develop into full-blown typhoons north and west of the state. The southernmost atoll in the state is Kapingamarangi, located 2° north of the equator, and subject to droughts, particularly during La Niña events.

**Chuuk**— From about November to June, the climate of Chuuk is influenced chiefly by northeasterly tradewinds with average monthly speeds of 8 to 12 mph. By about April, however, the trades begin to weaken, and by July give way to the lighter and more variable winds of the doldrums. Between July and November, the island is frequently under the influence of the ITCZ. This is also the season when moist southerly winds and tropical disturbances, many associated with the ITCZ, are most frequent, and when humidities often are oppressively high. Rainfall at Chuuk averages about 140 inches a year, and temperature is remarkably uniform; high temperatures are generally in the middle 80s, and low temperatures in the middle 70s.

Although the major typhoon tracks of the western Pacific lie to the north and west of Chuuk, several of the storms have passed close enough to the island to cause widespread damage, including Supertyphoon Nina in November 1987; Nina was the most intense and devastating storm to have struck the vicinity, and a few days later, it decimated the Philippines as well.



## FOCUS: THE 1997–1998 EL NIÑO— CLIMATE SCIENCE SERVING SOCIETY

The 1997–1998 El Niño event offers a vivid example of what climate means to people in the U.S.-Affiliated Pacific Islands (defined in Chapter One) and how information about potential consequences can be used to support decision-making and benefit society. This summary of the Pacific Islands' experience during the 1997–1998 El Niño comes from the work of the PEAC, which is a partnership among NOAA, the University of Hawai'i, the University of Guam, and the Pacific Basin Development Council.

By May 1997, most ocean-atmosphere observations and predictive models indicated that a significant El Niño was developing. El Niño events have significant consequences for U.S.-affiliated Pacific Islands, including droughts, changes in tropical storm/hurricane patterns, and changes in ocean conditions that affect economically significant resources like fisheries. For purposes of brevity, this example will focus primarily on El Niño-related changes in rainfall that led to severe drought conditions in many of the Pacific Islands.

In June 1997, PEAC alerted governments in the U.S.-affiliated Pacific Islands that a strong El Niño was developing and that changes in rainfall and tropical storm patterns in late 1997 through June 1998 might be like those experienced in 1982 and 1983. In September 1997, PEAC issued its first quantitative rainfall forecast, saying that severe droughts were likely beginning in December. PEAC also told governments that the risk of typhoons and hurricanes would be higher than normal in the RMI, eastern islands in the FSM, and in American Samoa. With the exception of Hawai'i, all Pacific Island governments served by PEAC developed drought response plans, aggressive public information and public education programs, and drought or El Niño task forces. The public information campaigns informed the public of what they might expect from El Niño, and what measures they could take to mitigate damaging consequences; these included water conservation, boiling water to prevent outbreaks of certain diseases associated with drought conditions, and reducing the risk of wildfires that often increase during drought conditions. In Pohnpei State for example, a video was produced and aired

on the public radio station four times a day; public service announcements were aired on local television and radio stations; information hotlines were set up; brochures were prepared and distributed, and presentations on El Niño and drought were made in local schools. Water management agencies in Majuro, Pohnpei, Chuuk, Kosrae, Yap, Palau, Guam and Saipan developed and implemented water conservation plans. In Palau, the Department of Public Works surveyed the water distribution system in Koror and completed repairs on about 80% of the system before the drought set in. Throughout the FSM, people repaired water catchment systems and local vendors were able to supply new household catchment systems to meet the demand that developed in response to the public information campaign. The FSM government made deliveries of water to outer islands in Chuuk and Yap. In November 1997, the FSM Congress appropriated \$5 million to address the potential impacts of anticipated drought conditions, and the U.S. Ambassador to the Republic of the Marshall Islands requested assistance from the U.S. Commander-in-Chief-Pacific (CINCPAC) to secure equipment and replacement parts to refurbish pumps for wells and increase storage capacity.

Even with these precautionary measures, the 1997–1998 El Niño produced such extensive drought conditions that water rationing became necessary in many areas. Water hours were imposed on most islands, with conditions on Majuro being the most severe. During April and May 1998, the water utility on Majuro was only supplying seven hours of water every fourteen days until pumps for wells on Laura islet were repaired. In Palau and Pohnpei, municipal water was available for only a couple of hours each day at the height of the drought. In the outer islands of Pohnpei, water was supplied by ship, and tanker trucks delivered water to schools in rural areas on the main island. Water supplied to the Koror-Airai area in Palau was reduced from 111 million gallons per month to 9.3 million gallons per month during the height of the drought.

*see "El Niño" on facing page...*

**Yap**— The ITCZ lies near Yap during the northern summer, particularly as it moves northward in July and southward again in October. At such times, showers and light, variable winds predominate, interspersed with heavier showers or thunderstorms, occasionally accompanied by strong and shifting winds. The average annual temperature is 81° F, and average annual rainfall is 121.5 inches. More than a quarter of all Yap's residents live on the outer islands, the rest on Yap.

Tropical cyclones or typhoons affect Yap much less often than they do Pacific Islands further to the north and west (the CNMI to the northeast, and the Philippines to the west and northwest, for example). June to December are

the months of greatest storm frequency, but fully developed typhoons are uncommon near Yap.

### *Guam*

The Pacific Ocean ends at Guam; its western shores signal the beginning of the Philippine Sea. This 209-square-mile island, southernmost of the Marianas, is the largest in Micronesia. Guam's climate is almost uniformly warm and humid throughout the year. Afternoon temperatures are typically in the middle to high 80s, with nighttime temperatures in the low 70s or high 60s. Relative humidity commonly ranges from 65 to 75% in the afternoon, and 85% or higher at night. Rainfall and wind conditions vary markedly, and it is these elements and variations that really define the seasons.

*"El Niño" continued...*

Agriculture suffered from the droughts everywhere except Guam. In the CNMI, citrus and garden crops were most affected, and the local hospital had to buy imported fruits and vegetables rather than rely on local suppliers. A limited damage assessment was done on Pohnpei, and serious losses of both food and cash crops were sustained. Losses of staple crops of taro and breadfruit in FSM exceeded 50%, and over half the banana trees evaluated had died or were seriously stressed. Sakau (kava) was probably the most serious economic loss because it had recently become a major cash crop. On Yap, taro losses were estimated at 50–65%, and betel nut prices increased more than 500% despite the fact that only 15–20% of the trees were lost. In Palau, food shipments increased from twice a month to once a week.

While the above example has focused largely on water, other climate-related consequences were felt throughout the islands; these included changes in the migratory patterns of economically significant fish stocks like yellowfin tuna, which resulted in losses for some island jurisdictions but opportunities for others; stresses on some coral reefs associated with increased temperatures; extreme tides from El Niño-

related variations in sea level, as well as increased sedimentation from erosion in areas affected by wildfires; losses of important fresh-water shrimp, eels and fish as rivers and streams dried up; and reduced local air quality conditions in areas such as Yap, Pohnpei, Palau and Guam, which were affected by increased wildfires locally and haze from wildfires in Indonesia.

Still, the consequences could have been worse. Advance warning made possible by emerging forecasting capabilities and a focused program of education and outreach clearly helped mitigate the negative impacts of these climate effects, a good example of how real people in real places can benefit from climate assessment and adaptation. Pacific Island communities, governments and businesses are learning how to factor new information about climate variability into their decisions and are now looking for information about how patterns of natural variability (like ENSO) might be affected by climate change in the long term. Scientists and decision-makers throughout the Pacific are learning how, by working together, they can begin to address the challenges and opportunities of climate variability and change (Hamnett, Anderson, Guard, and Schroeder, 2000).

There are two primary seasons and two secondary seasons on Guam. The primary seasons are the dry season, which extends from January through April, and the rainy season from mid-July to mid-November. The secondary seasons are May to mid-July and mid-November through December; these are transitional seasons that may be either rainy or dry, depending upon the climatic nature of the year. On average, about 15% of annual rainfall occurs during the dry season, and 55% during the rainy season.

Throughout the year, the dominant winds on Guam are the tradewinds, which blow from the east or northeast. The trade are strongest and most dominant during the dry season, when wind speeds of 15 to 25 mph are common. During the rainy season there is a breakdown of the trades, and on some days the weather may be dominated by westerly moving storm systems that bring heavy showers, or steady and sometimes torrential rain. Of all the countries and territories discussed in this report, Guam and the CNMI are most subject to typhoons, which are most frequent from June through November. Historically, Guam has been affected by as many as four typhoons in a single season. They occur most frequently during the latter half of the year, but they either strike or pass sufficiently close to produce high winds and heavy rains in every month.

### *Hawai'i*

Hawai'i's climate is one of the most spatially diverse on Earth. Because of this spatial variation of climate, Hawai'i resembles a continent in miniature. It has ecosystems

ranging from deserts to tropical rain forests and even subalpine mixed forests, all in very close proximity. Hawai'i is located in the tropics and surrounded by the Pacific Ocean, with the nearest continental land mass more than 2,000 miles away. The ocean supplies moisture to the air and acts as a giant thermostat, assuring small seasonal temperature variations. Hawai'i's warmest months are August and September, and its coolest months are February and March. For most of the state, there are only two seasons: the warm or "kau" season from April to September, and the cool or "ho'oilō" season from October to March. A semipermanent high pressure zone, usually northeast of the



*A billboard on Pohnpei encourages water conservation in preparation for the 1997–98 El Niño. (photo courtesy of U.S. National Weather Service, Pacific Region Headquarters)*





*The Intertropical Convergence Zone takes up residence around August and September of each year near Uliathi Atoll, in Yap, FSM.*

islands, provides the northeasterly tradewinds for which the state is famous. This high tends to be more persistent and stronger in the warm months, producing steady tradewinds and less rain. In the cool months, the tradewinds may be interrupted for days or weeks by the invasion of fronts, wind shear lines, or low pressure systems from the north, and by “Kona Storms”<sup>3</sup> near the islands. The cool season has more frequent southerly and westerly winds and more clouds and rainfall, sometimes producing flash flooding. Hawai‘i’s mountains, valleys and ridges significantly influence every aspect of its weather and climate (Sanderson, 1993).

Rainfall distribution closely resembles topographic contours; amounts are greatest over ridges and windward areas (northeast slopes of ridges and mountains) and least in leeward lowlands. The islands receive more than 400 inches of rain on Mt. Waialeale on Kaua‘i, more than 200 inches on higher windward elevations of all islands, and less than 15 inches in many leeward areas. The leeward and other dry areas have mostly dry warm months, and receive most of their rainfall from cool-season storms. The wetter regions show smaller seasonal differences because of the persistent tradewind showers. El Niño conditions usually disrupt this pattern, producing drought conditions, along with more frequent tropical storms and hurricanes. Tropical storms and hurricanes, although not frequent, have significantly affected the state in the late 1800s, 1959, 1982, and 1992 (Sanderson, 1993).

#### *Republic of the Marshall Islands*

The climate in the RMI is tropical, with tradewinds prevailing throughout the year. Tropical storms and typhoons are rare, although more likely during the summer

months and El Niño years. Tropical storms are more likely to produce damaging effects over the northern islands, but can affect the entire country. Minor storms of the easterly-wave type are quite common from March to April and October to November. The trades are frequently interrupted during the summer months by the movement of the ITCZ across the area. Rainfall is heavy, with the wettest months being October and November. Precipitation generally falls in showers, but continuous rain is not uncommon. One of the outstanding features of the climate is the consistent temperature regime; the range between the coolest and warmest months averages less than one degree. The average annual rainfall on Majuro (the most densely populated island, where the capital is located) is about 131 inches.

#### *Republic of Palau*

Precipitation is heavy in Palau, though variable from month to month and year to year. In Koror, where the weather station is located, annual rainfall of 150 inches or more is not uncommon. Normal monthly precipitation exceeds 10 inches, and in some years each month has received at least 15 inches. Precipitation is heavy during December and January, decreasing sharply when the ITCZ moves well south of the islands. February, March, and April are the driest months of the year. Winds are generally light to moderate, and the northeast trades prevail from December through March. During April, the frequency of tradewinds decreases, and there is an increase in the frequency of east winds. In May, the winds are predominantly from southeast to northeast.

The ITCZ usually moves northward across Koror during June, bringing with it heavy rainfall and thunderstorms that may yield an inch of rain in 15 to 30 minutes. The ITCZ remains in the vicinity of Koror, though most commonly northward, from July through January, with heavy rainfall persisting. Temperatures and humidity are high.

## **Model-based Scenarios of Future Climate Conditions**

This section provides a brief technical discussion of the results of recent efforts to anticipate future climate conditions using complex computer models that simulate the behavior of key components of the earth’s climate system. These projections of future climate change for the Pacific Region are based on two approaches. The first approach uses a single, global, coupled ocean-atmosphere model to project

<sup>3</sup> A “Kona storm” is a low-pressure system that develops in the upper troposphere, gradually extends to lower altitudes, and may eventually appear as a low at the earth’s surface. Kona storms form near the Hawaiian Islands every year, but locations and effects vary. If a Kona storm develops to the west of Hawai‘i, moist showery southerly winds may persist for more than a week and rainfall totals are often large. Kona storms forming to the east of the Hawaiian Islands tend to bring rain that falls largely over ocean areas (Sanderson, 1993).

seasonal changes for the Pacific Region. This single-model approach has been supplemented with a review of the results of a multimodel ensemble used in the third assessment report of the Intergovernmental Panel on Climate Change (See Cubasch et al, 2001 for details on the models and emissions scenarios).

The single-model climate change projections shown here are based on the results from two models: the Hadley model run at the Hadley Center for Climate Prediction; and the first-generation, coupled, general-circulation model of the Canadian Center for Climate Modeling and Analysis.

These two models were run for 100+ years, ending in 2100, using the core greenhouse-gas emissions scenario for the National Assessment, which is a 1% rate of annual increase in CO<sub>2</sub>, and commensurate changes in sulfate aerosols (the GHG+A scenario). The 1% rate of increase is based on rates of observed increases modified by estimates of how the current sources of emissions are likely to change in the future; as such, it is deemed plausible as a “business as usual” case with little policy intervention anticipated in the future.

In these models, increased CO<sub>2</sub> causes warming by limiting outgoing long-wave radiation in the absence of a simultaneous reduction in incoming solar radiation. Increased sulfate aerosols produce a net cooling over regions where sulfur emissions are greatest, generally corresponding to industrial regions in the midlatitudes of the northern hemisphere. The “direct effect” of these aerosols (reflection of some of the incoming solar radiation before it can reach the earth’s surface) is accounted for in the models, but the radiative forcing of increased aerosols is weaker than that of the CO<sub>2</sub>, so by the end of the 21st century a general (but not spatially uniform) warming of the globe is projected to occur. Additional information on these model emission scenarios is provided at the web site (<http://www.cgd.ucar.edu/naco/emissions.html>).

As the results from the Hadley and Canadian models were generally consistent, all figures in this report’s discussion of specific results will be from the Hadley model; comparisons with Canadian results will be made if necessary. In general, the details of important Pacific Island climate processes such as ENSO were better resolved in the Hadley model, thus the rationale for using the Hadley results in these figures.

The multimodel ensemble summary in this report represents an average of nine “state-of-the-science” global, coupled climate models from groups in the U.S., Canada, Germany, Australia, the U.K. and Japan. The multimodel

ensemble was run with two of the scenarios (A2 and B2) described in the IPCC Special Report on Emissions Scenarios (SRES). The multimodel ensemble results shown here present annual means. The comparison of detailed seasonal results from the Hadley model with the annual mean multimodel results provides a comprehensive picture of the types of climate changes projected to occur in the Pacific during the 21st century. In addition, the ensemble method provides scientists with a tool for quantifying levels of uncertainty among the models’ projections of changes in key climate variables, such as surface temperature and precipitation. The use of multimodel ensembles for this purpose is briefly described in a sidebar that precedes this chapter’s summary.

## Climate Change Projections from a Single Model

The following sections describe the results of the single model-run for temperature, rainfall, ENSO, tropical cyclones and sea level for the Pacific Islands addressed in this Report. Two time periods were used in the analysis of future changes in temperature and rainfall:

- average conditions from 2025–2034 minus the model’s 1961–1990 base-period average (called “short-lead” in the figure captions); and,
- average conditions from 2090–2099 minus the model’s 1961–1990 base-period average (called “long-lead” in the figure captions).

Long-lead results for the 2090–2099 period are more uncertain and speculative than those for the 2025–2034 period, although they may sometimes serve to amplify and further define the same patterns shown in the short-lead results. The two seasons analyzed are December-January-February (DJF) and June-July-August (JJA). These are thought to represent the two seasonal extremes. However, changes in certain phenomena, such as tropical cyclones that peak during the transition seasons, may not be optimally represented.

### Temperature

The primary effects of climate change in the tropical Pacific Basin are projected to be a gradual warming of the sea-surface temperature (SST) and the air temperature. About 1° C (1.8° F) of warming is projected per 20 to 45 years. As shown for the Hadley model in Figures 2.1 (2025–2034) and 2.2 (2090–2099), warming in this model is projected to be greater in the following areas: a region along and slightly south of the equator extending from the international dateline on the west to the South American coast on the east, and in the region that extends east-northeastward from the equatorial Central Pacific to the

United States-Mexico border and the southwest coast of the United States. The area of warming generally resembles a horseshoe-shaped pattern that is concentrated north and slightly south of the equator east of the dateline.

The warming in the equatorial East Pacific is projected to be greater during the peak El Niño season of DJF. Hawai‘i is on the northern edge of the fastest warming area in the northern leg of the horseshoe, with projected increases in SST of 1.3° C (2.3° F) by the 2025–2034 period (Figure 2.1) and 3.0° C (5.4° F) by the 2090–2099 period (Figure 2.2). The outer edges of the east-southeastward leg of the horseshoe affects American Samoa, the northern Cook Islands and French Polynesia, with projected increases in SST of 0.5° C (0.9° F) by 2025–2034 and 1.3 to 2.0° C (2.3 to 3.6° F) by 2090–2099.

The projected warming pattern for the Canadian model is in general agreement with the Hadley model, with somewhat warmer temperatures along the northern and southern legs of the horseshoe pattern, reaching 1.6° C (2.9° F) in the short-lead results, and 4 to 5° C (7.2 to 9½ F) in the long-lead results.

### Rainfall

Accompanying the warming in the Hadley model, certain parts of the region are projected to experience increases in rainfall due to the fact that warmer water produces more moisture and the atmosphere above a warmer ocean surface can absorb and hold more moisture. The most likely locations for increased rainfall are near the equator in the vicinity of the dateline, where the SST is already nearly warm enough to support convection (cumulus cloud growth and precipitation).<sup>4</sup> Any additional increase in ocean temperatures in these areas, then, would result in marked increases in

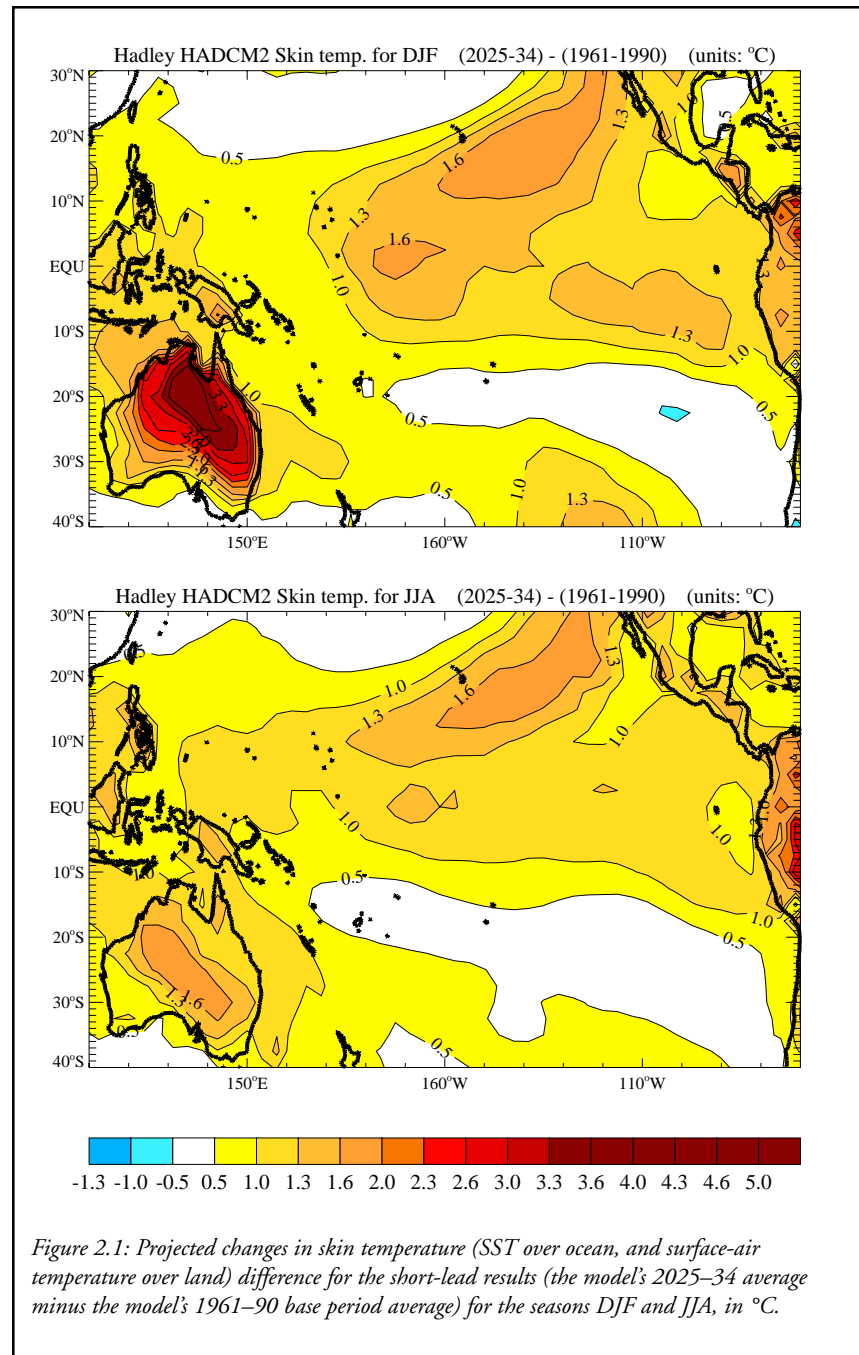
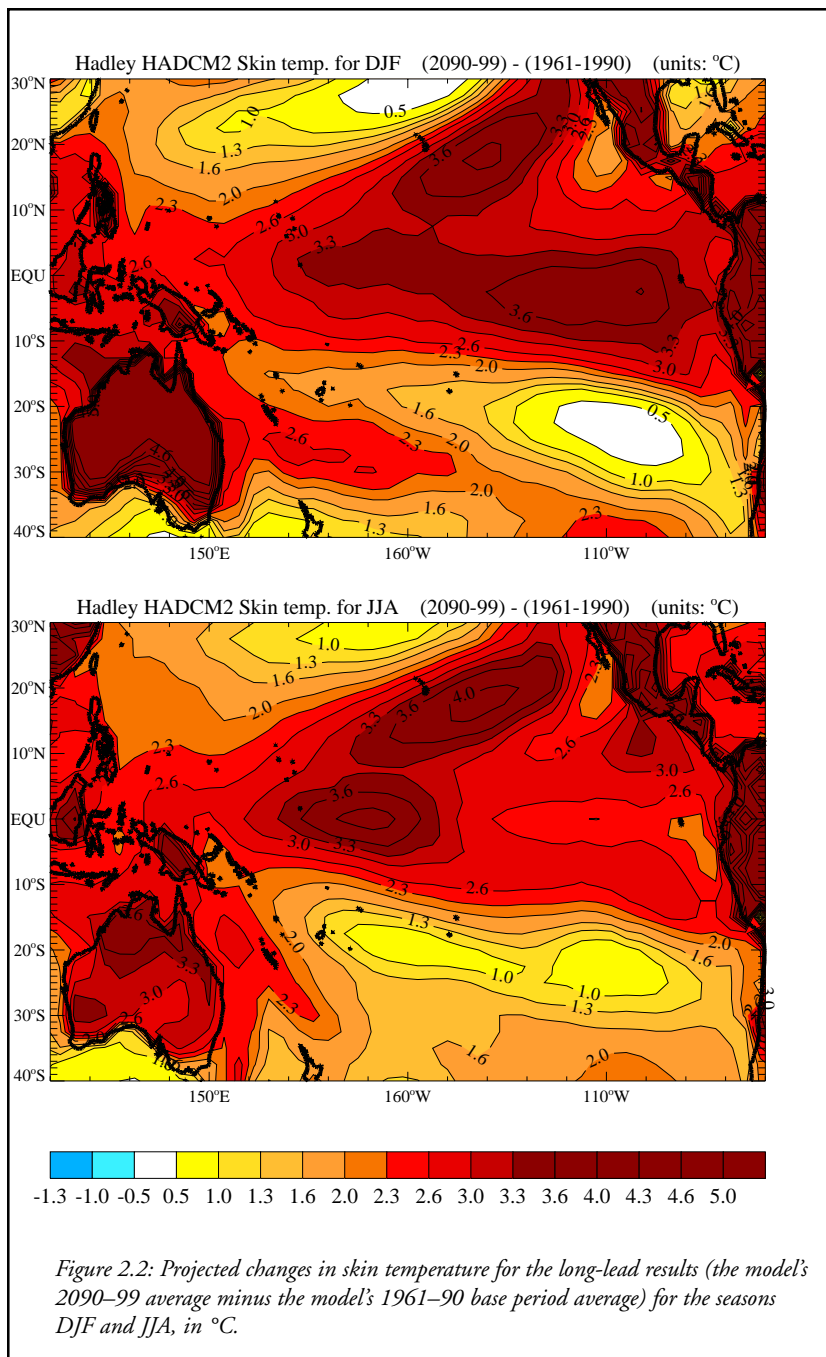


Figure 2.1: Projected changes in skin temperature (SST over ocean, and surface-air temperature over land) difference for the short-lead results (the model's 2025–34 average minus the model's 1961–90 base period average) for the seasons DJF and JJA, in °C.

convection, and therefore rainfall. It is important to note that, during an El Niño, the SST in these equatorial regions near the dateline exceeds the temperature threshold for convection. Increased rainfall is therefore projected along the two warming “arms” of the horseshoe-shaped temperature pattern described above.

<sup>4</sup> Convection refers to the process of cloud formation and precipitation associated with areas where warm, tropical air rises through the atmosphere and, as it expands and cools, leads to the formation of clouds—a process through which latent heat is added to the atmosphere as water condenses to form clouds. As a result, weather tends to be disturbed in these areas. In the tropics, warm air rises to the top of the troposphere and moves off toward the poles. These areas of “rising” air movement are complemented by areas in which colder air tends to move downward through the atmosphere (“sinking” air), and then toward the equator. Alternating areas of rising and sinking air are found around the globe between the poles and the equator, and help characterize the world’s weather zones. As a general rule, weather in areas of sinking air tends to be dry and relatively calm.



Scientists expect seasonal variations in this anticipated rainfall pattern. For example, they do not project any significant change in winter, when ocean temperatures are cooler in areas to the east of the horseshoe's vertex (the place where the curve in the horseshoe is the sharpest—in this case, where it crosses the equator). During the boreal summer months of June, July and August, increased rainfall is projected to occur along a line from the equatorial vertex (near Kirabati) all the way to the southernmost Hawaiian island. Model projections for 2025–2034 (Figure 2.3), indicate that areas of increased rainfall in the horseshoe in the southern hemisphere extend to 10° south, on a line stretching from Kirabati at the equator to American Samoa.

The results for the period 2090–2099 (Figure 2.4) show this area extending further south to between 15 and 20° south, with the largest increases in precipitation along a line extending from RMI in the north to Tahiti in the south. The regions near 10° north and to the west of the dateline (e.g. FSM) would also receive substantially greater precipitation in the long-lead results than in the short-lead results.

During the austral summer months of December, January and February, the increased rainfall is tantamount to an intensification of the South Pacific Convergence Zone, an area of the ocean that provides one of the principal sources of heat, and therefore energy, to the atmosphere. Model projections for 2025–2034 (Figure 2.3), indicate enhanced rainfall along a broad band extending from 10° north and 160° east (including the easternmost islands of Micronesia and the RMI) through the equatorial dateline and southeast to near 10° south and 130° west, near the Marquesas Islands. This region of enhanced precipitation is further enlarged in the projections for 2090–2099 (Figure 2.4), with increased rainfall extending further east along the equator, and large increases near the Marquesas Islands. This area also extends further westward to encompass the westernmost islands of Micronesia.

Decreased precipitation could be experienced in all seasons in areas near the equator east of about 140° west longitude (e.g., Fanning and Christmas Islands).

Since rising air must fall somewhere else (see Footnote 4), areas of rising air (usually accompanied by cloud formation and rainfall) alternate with neighboring areas of sinking air that tend to be relatively dry. For this reason, dryness could also increase poleward of the most rapidly warming equatorial regions, such as north of the Hawaiian Islands, affecting many of the AF/USAPI west of Hawai'i, and tropical South Pacific Islands farthest off the equator but west of French Polynesia. This would imply that, except for the boreal summer season in the long-lead results, where there is greater precipitation, the western portion of the FSM would become drier, for example in Yap and Chuuk. The eastern part of the FSM (possibly Pohnpei, but more



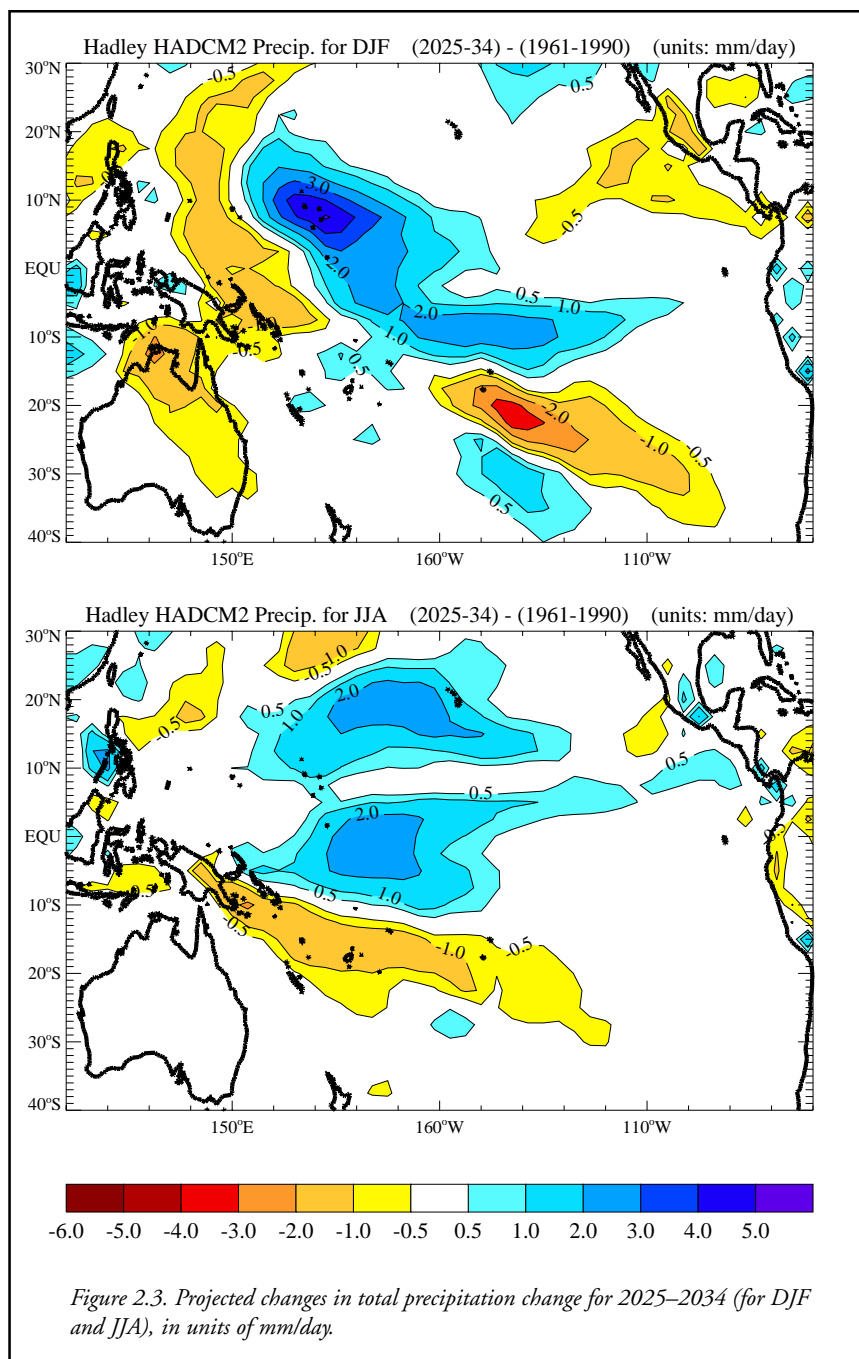
likely Kosrae) not only could be exempt from this drying trend, but could become wetter, being closer to the rain-producing warmed SST near the dateline. South of the equator, island areas such as New Caledonia, Vanuatu, Fiji, southern Tonga, and Niue could become drier.

All these possible rainfall-change scenarios are more uncertain than the temperature-increase scenario and should therefore be considered cautiously. The exact location of the borderlines between neighboring regions of enhanced rainfall and suppressed rainfall is particularly uncertain. This uncertainty will be discussed in more detail later, in the context of results from the multimodel ensemble experiments. Some of the locations near the boundary between the regions made alternately wetter and drier by El Niño appear also to be on the boundary for the rainfall effects of climate change; examples of such locations are Apia in Samoa, and Nialakita in southern Tuvalu.

The patterns for projected precipitation changes in the Canadian model are generally similar to those in the Hadley model. The differences include somewhat stronger reductions in precipitation over the Western Pacific for the short-lead results in the Canadian model, as well as a generally noisier pattern of precipitation changes (small-scale variations between positive and negative precipitation changes) in the Canadian model for much of the region west of the dateline and south of 20° north; this encompasses much of the area around the FSM, the RMI and south to Fiji.

### Natural Variability/ENSO

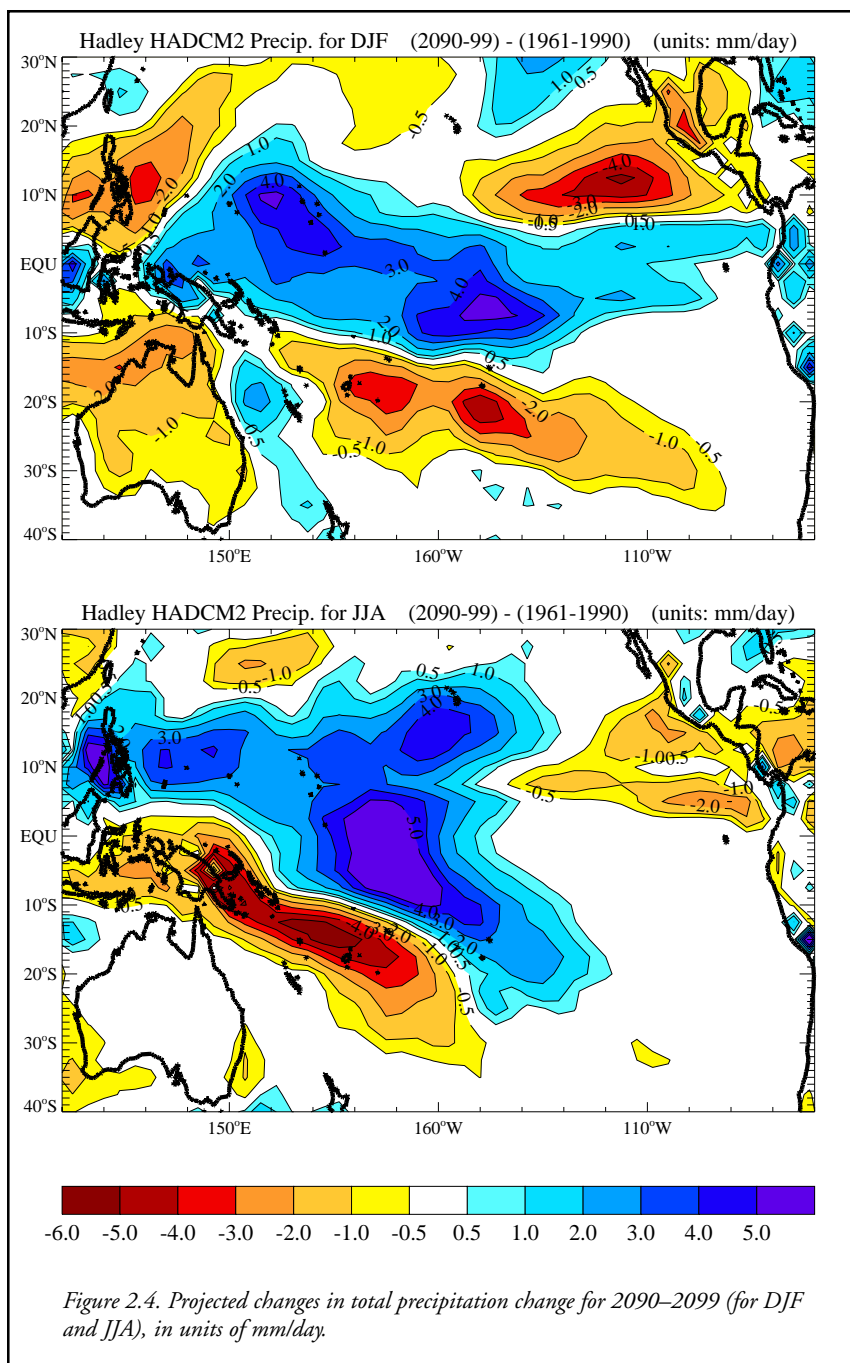
In the Hadley model, the pattern of increased SSTs along the equatorial Central and Eastern Pacific suggests a greater tendency for El Niño-like conditions, with SSTs steadily warming in the Central and Eastern equatorial Pacific Ocean. The increase of precipitation in this same region is indicative of the warming pattern seen in the model results in DJF for both the short- and long-lead results. In this analysis, anomalies of SSTs in the Niño-3 region (defined



as 5° N to 5° S and 150° W to 90° W) are used to measure the strength of El Niños and La Niñas. The time-series of the Niño-3 SST anomaly index from the Hadley model (Figure 2.5) shows a general warming trend through 2099, with the average SST increase in this region of almost 3° C (5.4° F).

However, the background setting for the ENSO phenomenon may be altered somewhat, with effects that are difficult to project. That is, the character of ENSO itself may change with the overall warming of the ocean and atmosphere. This creates some uncertainty about the details of the future climate conditions in the Pacific. Presently,





some models project an increase in El Niño amplitude, and some show little change or a slight decrease (Cubasch et al.,

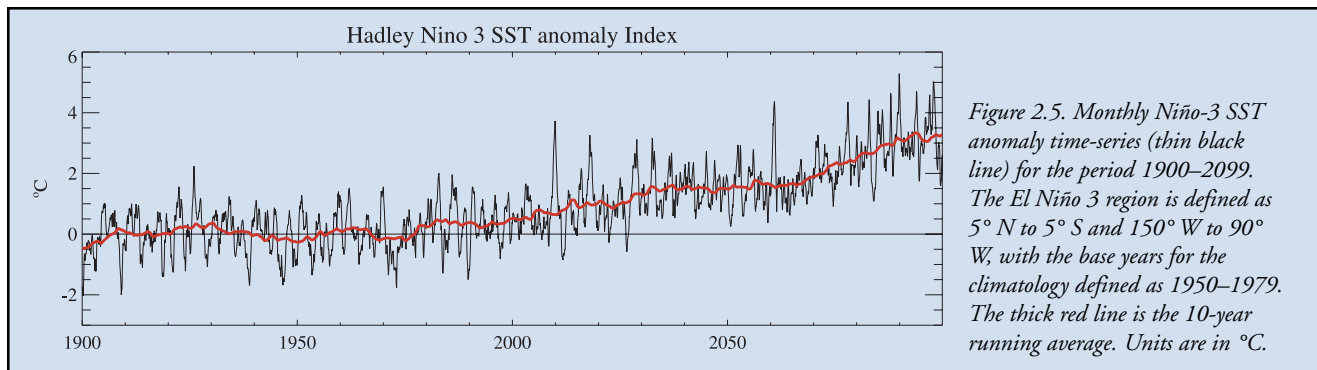
slightly. In that case, the overall result would be an eastward extension of the tropical region that would

2001). This is actively being examined by the research community, but limitations in the models' ability to simulate ENSO restricts the certainty of projections of El Niño behavior.

### Tropical Cyclones

Pacific tropical cyclones generally develop over ocean water that exceeds roughly 28° C (82.4° F). During the past 30 years, such warm water has generally been limited to the Western tropical Pacific, which has been the source of most cyclone activity. This region extends farther east than usual during El Niño, posing an increased cyclone threat to islands farther east. The cyclones normally develop somewhat north or south of the equator and to the west of the dateline, and initially move toward the west with the tradewinds. They then curve poleward and finally eastward, threatening islands well off the equator, such as Guam, the RMI, or the Hawaiian Islands.

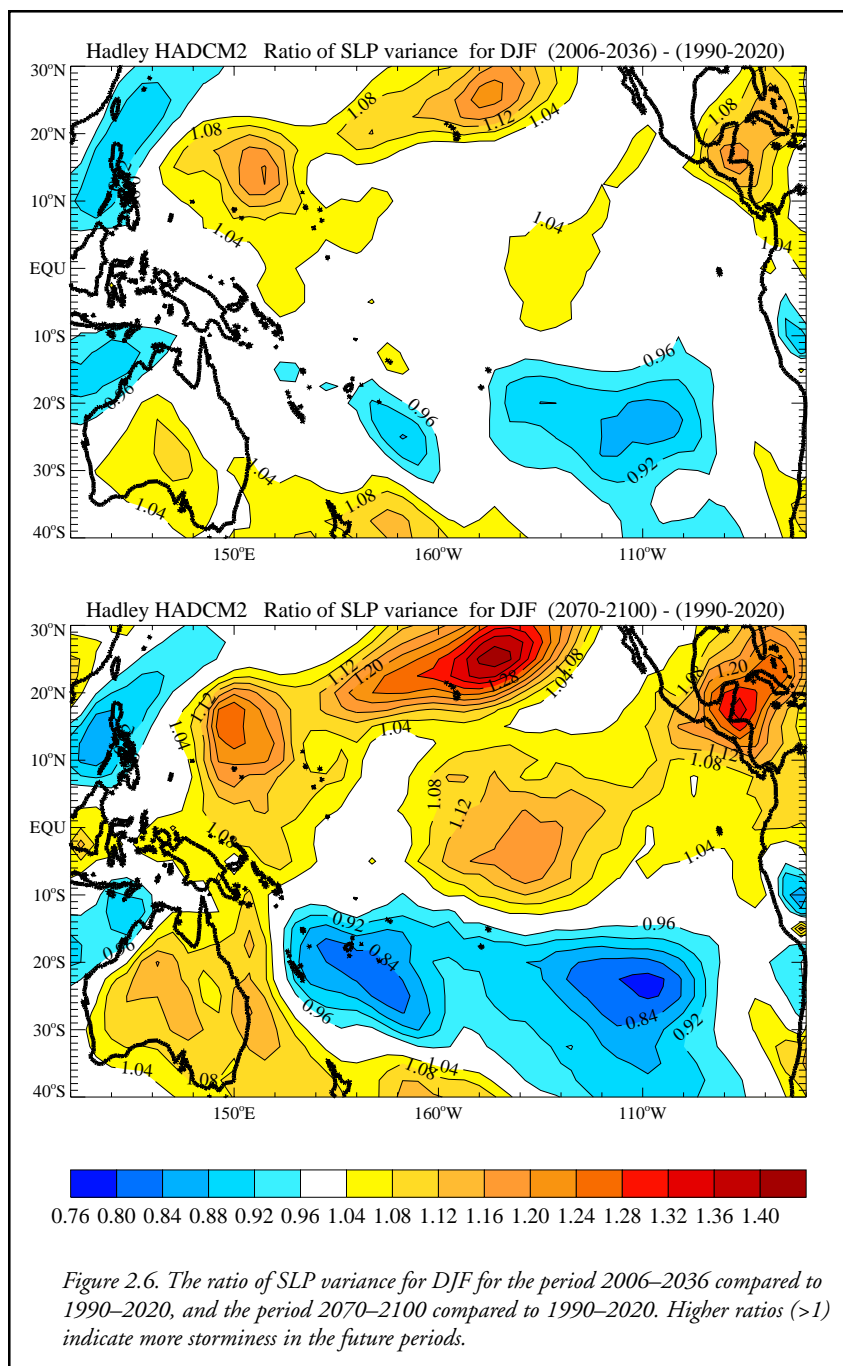
With global climate change, the region of very warm ocean water is projected to expand farther toward the east into areas that now expect warm water only during El Niño. The projected result is a gradual increase in the frequency of tropical cyclones for islands in the Central and East-Central Pacific, both north and south of the equator. Storm frequencies for the far Western Pacific may not decrease as they would presently during El Niño events, because the SST there will also be increasing, albeit at a slower rate. In fact, the frequency could increase



normally experience cyclones, especially during the local summer and fall, when they are most likely. However, none of the global coupled climate models currently in use, including the Hadley, have sufficient spatial resolution to accurately simulate individual tropical cyclones. Experiments with embedded hurricane models in the global models suggest a slight intensification of tropical cyclones with more intense precipitation and somewhat higher peak wind-speeds in a warmer future climate (Cubasch et al., 2001).

Large-scale midlatitude storms are a function of the frequency and intensity of cyclonic activity, which must be computed from frequent (usually daily) measurements. Storms cause large changes in sea-level pressure (SLP) on a short time scale and, as a result, intraseasonal variation in SLP is an indicator of storminess—low pressure systems and their fronts in the extratropics, and tropical cyclone activity in the tropics. The Hadley data are calculated as standard deviations of SLP, filtered with a Murakami filter that isolates the synoptic variability between 2.5 and 8 days.

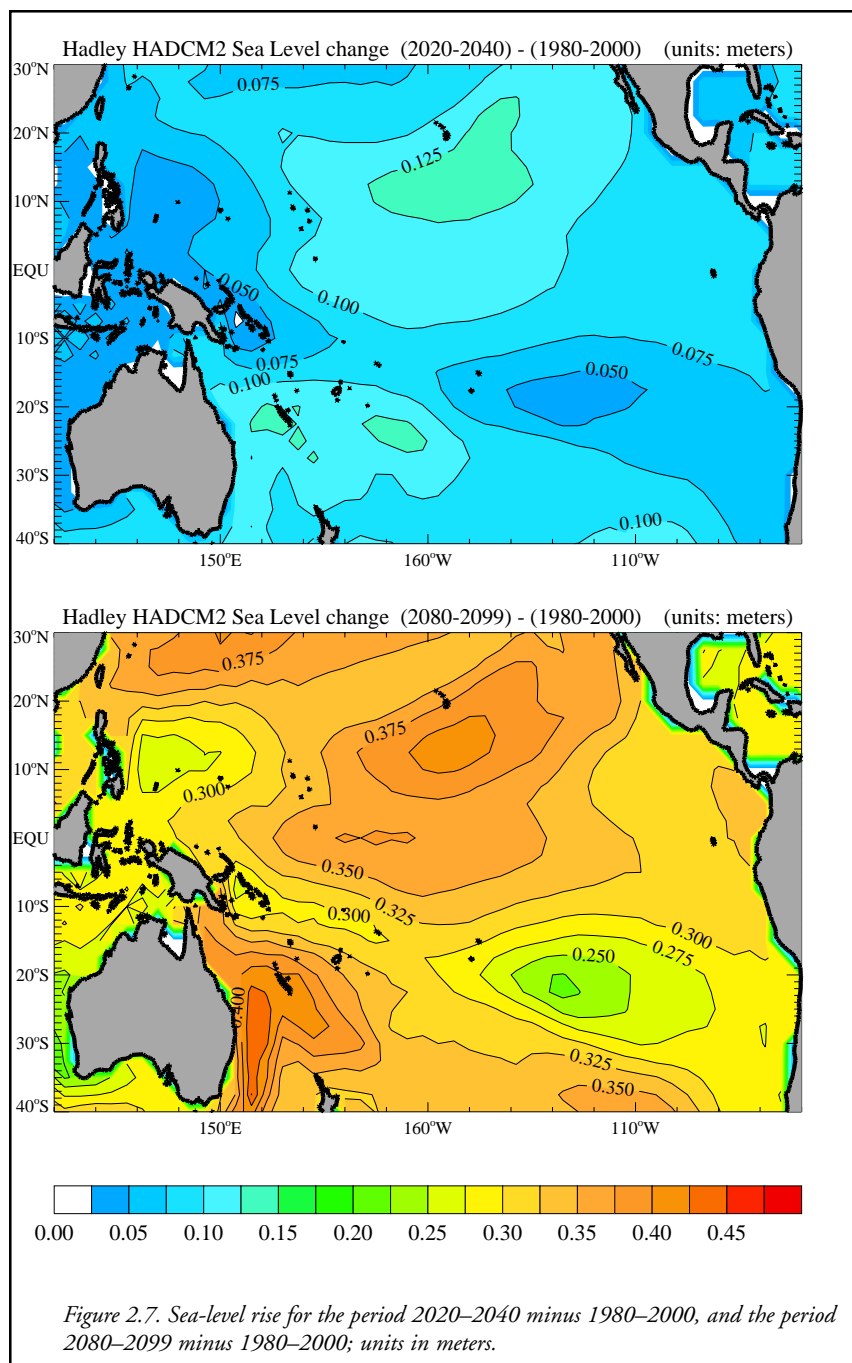
Figure 2.6 shows projected changes in the ratio of SLP variance for two periods (2006–2036 and 2070–2100) compared to a baseline period of 1990–2020 in the Hadley model. Figure 2.6 illustrates that in the near future more storminess is projected for a region extending north and east of the Hawaiian Islands to the area north of the FSM and east of the CNMI. For the far future (2070–2100), the storminess in this region is enhanced further and enlarged to encompass the entire Hawaiian Islands as well as most of the FSM and the RMI. The equatorial region between 100° west and the dateline (north of the French Polynesian Islands but including the Marquesas Islands) is also expected to experience more storminess in the far future. In the southern hemisphere between 10° and 30° south, storminess is projected to decrease for regions between 170° east and 90° west, which would include Fiji and the French Polynesian Islands. The area surrounding American Samoa is near the zero-line separating the regions of increased or decreased storminess in the far future.



### Sea Level

While increased sea-level rise can disrupt coastal areas over much of the Earth, atolls are particularly vulnerable to the phenomenon. Entire Pacific nations and archipelagos have maximum elevations of no more than two meters above sea level; even a relatively small sea-level rise could affect a large fraction of island area.

Sea-level rise can result in the loss of low-lying coastal areas—including agricultural land, human settlements and valuable ecosystems—through erosion and inundation. Sea-level rise also can accelerate reduction in the volume of



the fresh-water lenses of low-lying atolls, further stressing fresh-water resources that may already be affected by reduced rainfall. Higher sea level conditions could also exacerbate the damaging effects of tropical cyclones and storm surge.

Sea-level rise and climate change can accelerate beach erosion and also affect other forms of natural protection such as mangroves and coral reefs. Some recent studies suggest that the “net effect of sea-level rise on mangroves is unclear,” noting that if the rise is gradual, the effect could be beneficial for mangroves in some sites (World Bank,

2000). On the other hand, the potential loss of coral reefs from SSTs rising above the coral’s preferred temperatures could jeopardize the natural protection afforded by the reefs, and thus exacerbate the shoreline effects of wave action as well as periodic and long-term variations in sea level; this could also be influenced by other factors associated with climate change. For example, a possible reduction in the rate of coral reef growth as a result of an increase in carbon dioxide (CO<sub>2</sub>) in seawater could mean that these natural protective barriers will be unable to keep up with sea-level rise, thus exposing shoreline areas to storm surge and wave energy that would otherwise have been dissipated by the reef. Loss of freshwater resources associated with saltwater intrusion as a result of sea-level rise could also be exacerbated by other factors affecting the availability of freshwater such as changes in rainfall or patterns of natural variability such as El Niño.

As these examples illustrate, it is important to recognize that any accelerated sea-level rise associated with climate change will be accompanied by other changes whose combined effects should be understood and addressed.

For the Hadley model, the sea-level change for the two periods analyzed is shown in Figure 2.7: 2020–2040 minus 1980–2000, and 2080–2099 minus 1980–2000. The model-based scenarios used in the National Assessment project a sea-level rise of between 10 and 12 cm (3.9 to 4.7 inches) for much of the

tropical Pacific for the short-lead results, and a rise of between 30 and 38 cm (11.8 to 15.0 inches) for the long-lead results.

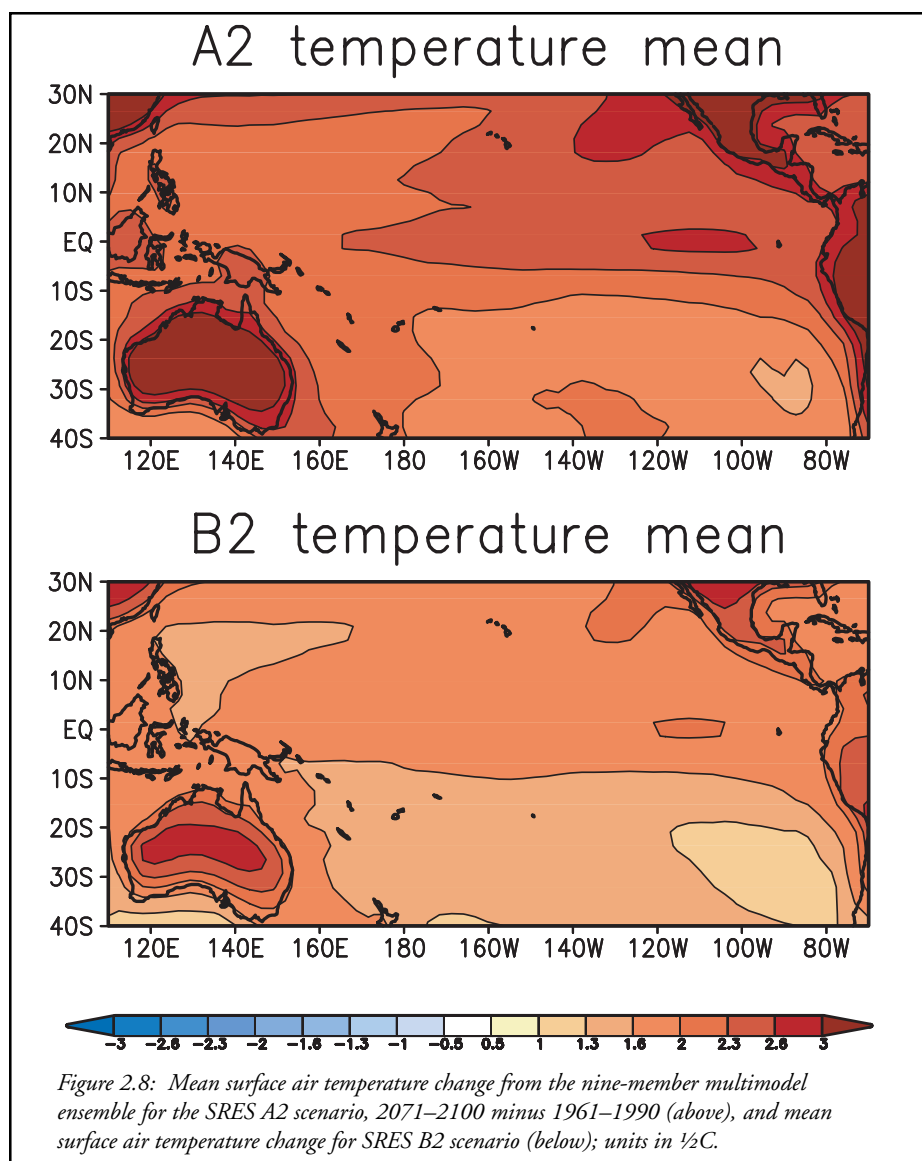
The worldwide, eustatic sea-level change shown in Figure 2.7 represents thermal expansion and glacial melt, but not ice-sheet melt because of the uncertainty of the net effect of climate change on Antarctic and Greenland ice sheets. Sea-level rise varies with location because of local heating and thermal expansion. Isostatic rebound and subsidence must be factored in when using these values to compute relative sea-level rise at a particular location.

It should be noted that projections of sea-level rise depend crucially on the choice of future emissions scenarios. Using the full range of 36 scenarios summarized in the IPCC Special Report on Emission Scenarios (SRES), the IPCC Third Assessment Report projects a rise in sea level ranging from 9 to 88 cm (3.5 to 34.7 inches) at the end of the 21st century (Church et al., 2001). The single-model results presented here use only one emissions scenario, and should therefore be evaluated in this broader context.

To provide some historical perspective for these projected changes, Table 2.3 (see page 34) provides a summary of mean sea-level trends at selected stations in the Pacific Islands covered by this Report. In addition, it must be noted that some Pacific Islands experience significant short-term variations in sea level associated with ENSO events. For example, sea level at Kwajalein is reported to have dropped 20 cm (7.9 inches) during the 1982–1983 El Niño. The University of Hawai‘i’s Pacific Sea Level Data Center notes that for one tidal station in the western Pacific (at Malakal, Palau), sea level dropped 15 cm (5.9 inches) below the long-term average during the 1997–1998 El Niño, and rose almost 30 cm (11.8 inches) above normal during the La Niña that followed.

### Climate Change Projections from a Multimodel Ensemble

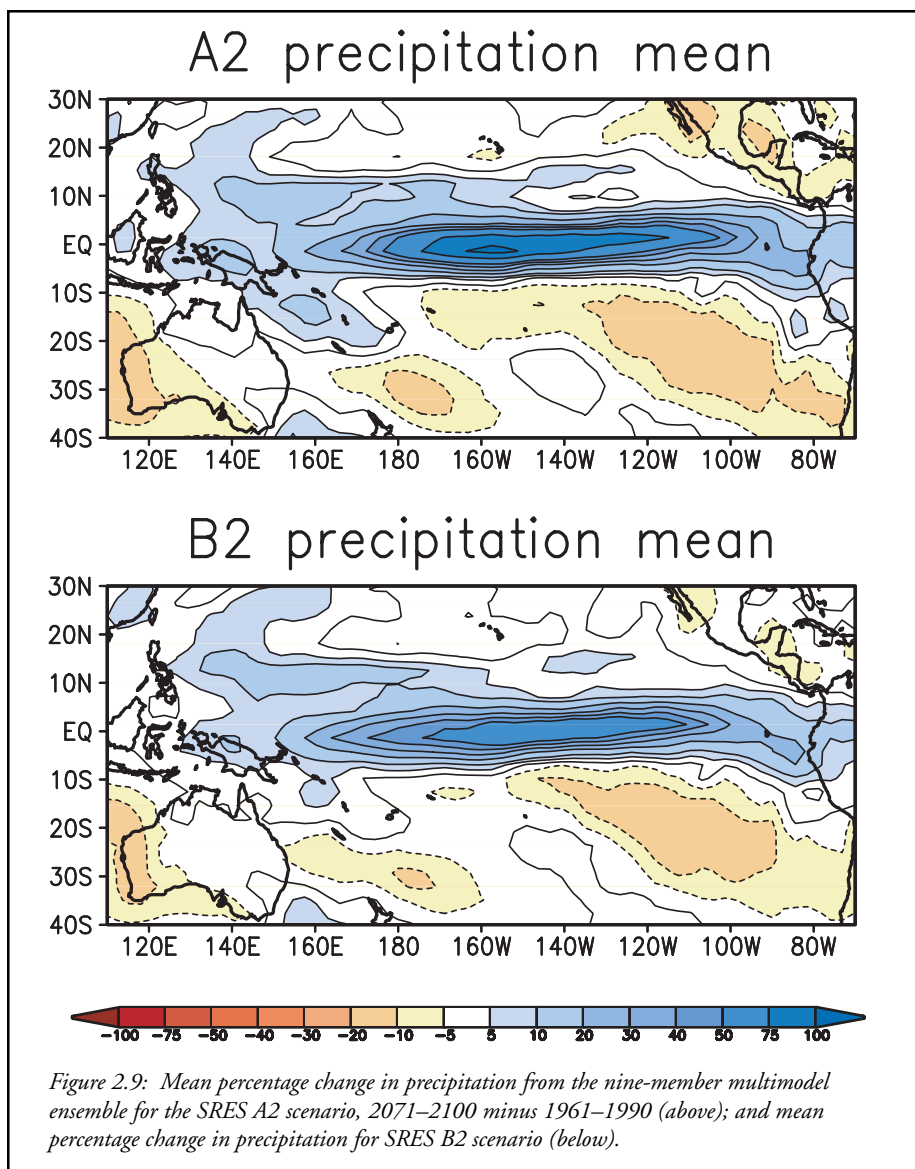
Annual mean surface temperature change for the nine-member multimodel ensemble is shown in Figure 2.8 for the end of the 21st century (years 2071–2100 minus 1961–1990) for two of the emissions scenarios (A2 and B2) used in the IPCC SRES. The main difference between the scenarios used in the multimodel ensemble and the scenario used for the Hadley model above is that the more recent SRES estimates for future sulfur emissions have been reduced, thereby producing less negative radiative forcing



from that source, and allowing more warming from the increase in greenhouse gases. The patterns of warming caused by sulfate aerosols do not substantially affect the Pacific Region since they are restricted mainly to industrial areas. The other differences between the A2 and B2 scenarios are that A2 generally has greater increases of greenhouse gases, and thus more positive radiative forcing than B2. Therefore, the climate changes in A2 are generally greater than in B2, and the net radiative forcing is less than in the scenario used in the Hadley model, which is closer to the A2 scenario.

The multimodel ensemble results both show a general warming of the tropical Pacific in agreement with the Hadley model, with greater warming east of the dateline relative to the Western Equatorial Pacific (see Figure 2.8). This so-called “El Niño-like response,” noted above, is stronger in scenarios in the multimodel ensemble than in





the Hadley model, with surface temperature increases greater than 2° C (3.6° F) in B2 and 2.6° C (4.7° F) in A2 in the equatorial Pacific.

The implications of these surface-temperature changes are reflected in the changes in annual mean precipitation in Figure 2.9. The mean “El Niño-like” surface-temperature changes produce a similar El Niño-like change in precipitation, with an eastward shift of anomalous precipitation; they also produce increases approaching 100% in the equatorial Pacific near 160° W (just north of American Samoa) in A2, and greater than 50% east of the dateline in B2 (see Figure 2.9). Since the surface-temperature changes in the multimodel ensemble are more concentrated east of the dateline near the equator, areas in which precipitation increased more than 10% are confined mainly east of about 160° E and between about 5° N and 5° S, in a region just north of the Marquesas Islands. The Hadley precipitation

changes extend more broadly in latitude, and occur farther west. For both A2 and B2, areas of decreased precipitation in the multimodel ensemble are projected to occur around French Polynesia and westward to near Fiji, and also near Hawai‘i, though those decreases are about 10% or less.

### The Use of Multimodel Ensembles to Quantify Uncertainty

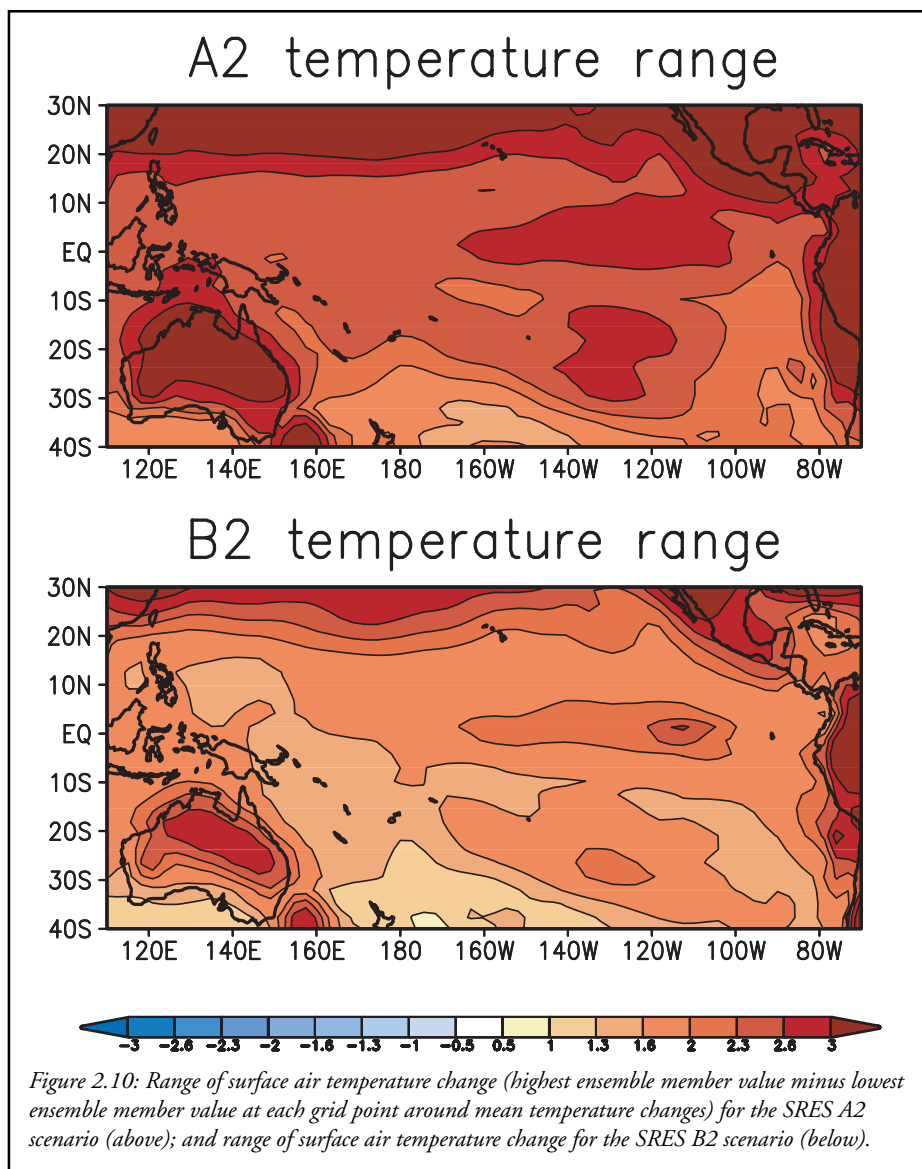
Scientists can use multimodel ensembles like the ones described here to help quantify levels of uncertainty in model-based projections of climate change. The greater the agreement— or consistency— among models in an ensemble, the more confident a scientist will be about a projection. To provide an idea of model consistency, or conversely, of the level of uncertainty associated with climate change projections, the range of model responses for surface-



temperature increase across the tropical Pacific is around 2 to 3° C (3.6 to 5.4° F) in A2, and 1.5 to 2° C (2.7 to 3.6° F) in B2 (see Figure 2.10). The range is less and thus the consistency among the nine models is generally greater in the equatorial tropics between 20° N and 20° S. As in the Hadley model, there is a relative maximum of warming projected to occur in a band extending through the Hawaiian Islands, with a relative minimum in the Southeast Pacific south of about 15° S.

Another measure of model uncertainty in the trajectory of the indicated change that scientists use is the multimodel signal divided by the multimodel standard deviation at every grid point. Where these values are greater than 1.0, the multimodel climate changes are more consistent relative to the noise. For annual mean temperature differences in the multimodel ensemble, all areas in the Tropical Pacific have signal-to-noise values greater than 1.0 (not shown), indicating significant model consistency for the temperature changes shown in Figure 2.8.

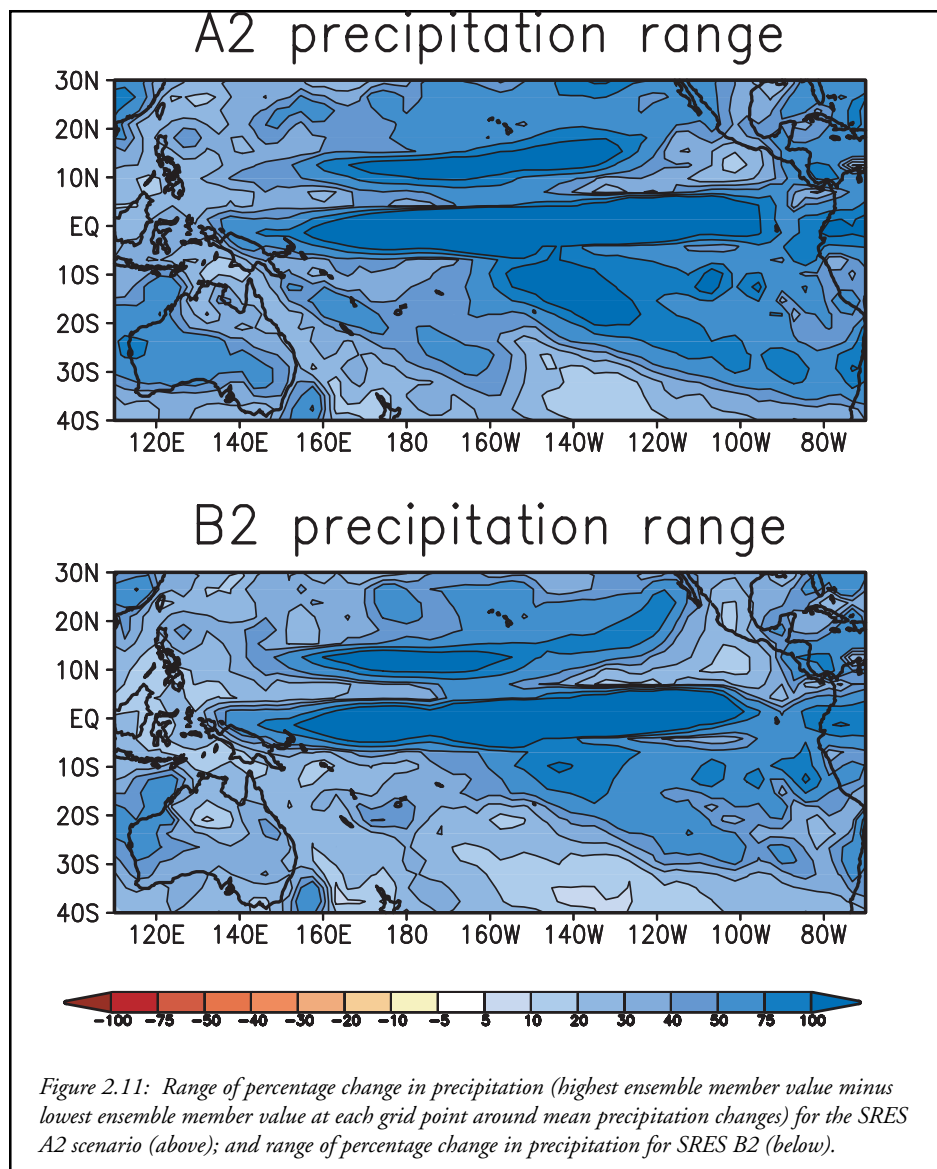
As noted for the Hadley model, precipitation projections are much more uncertain than temperature projections. The range of precipitation changes for A2 and B2 exceed 200% in the Equatorial Pacific for both scenarios, with smaller values to the north and south (see Figure 2.11). Additionally, the signal-to-noise calculation for the multimodel ensemble has values greater than 1.0 only in a few regions of the Western Equatorial Pacific (not shown). Thus there is much more scatter among the model results, and therefore greater uncertainty, about precipitation compared to temperature.



## Summary

The model-based climate-change scenarios reviewed in this chapter highlight the following important issues that were central to discussions of vulnerability in the Pacific Assessment:

- a general warming trend in surface air temperatures across the region, with implications for human settlements and marine and terrestrial ecosystems;
- a net regional enhancement in the hydrological cycle with a trend toward higher precipitation in some areas, but with important subregional differences that include drier conditions in some areas and uncertainties about the potential effects of changes in hurricanes and tropical storms that often provide a large percentage of rainfall in certain areas;



- potential changes in natural climatic variability, including the possible emergence of a persistent El-Niño-like condition that could affect rainfall, tropical storms and ocean conditions, and, in turn, economically important fisheries and coral reefs;
- potential changes in hurricanes and tropical cyclones associated primarily with variations in SST and with possible changes in ENSO, as well as long-term changes in the normal SST;
- increased ocean temperatures, with implications for temperature-sensitive resources like coral reefs and fisheries; and,
- changes in sea level, including both periodic changes associated with ENSO events and a long-term rise in sea level.

**Table 2.3: Mean Sea Level Trends at Selected Pacific Island Stations.**

Location	Rate of Change	Record Duration	Total Change
<b>Hawaiʻi</b>			
Honolulu	1.5 +/- 0.2 cm/decade (0.6 +/- 0.1 in/decade)	1905Ð 2000	14.2 +/- 1.9 cm (5.6 +/- 0.8 inches)
Hilo	3.2 +/- 0.5 cm/decade (1.3 +/- 0.2 in/decade)	1927Ð 2000	23.9 +/- 3.7 cm (9.4 +/- 1.5 inches)
Nawiliwili	1.4 +/- 0.4 cm/decade (0.5 +/- 0.2 in/decade)	1954Ð 2000	6.4 +/- 1.9 cm (2.5 +/- 0.7 inches)
Kahului	2.1 +/- 0.5 cm/decade (0.8 +/- 0.2 in/decade)	1950Ð 2000	10.8 +/- 2.6 cm (4.2 +/- 1.0 inches)
Mokuʻoʻlo	0.8 +/- 0.5 cm/decade (0.3 +/- 0.2 in/decade)	1957Ð 2000	3.5 +/- 2.2 cm (1.4 +/- 0.9 inches)
<b>Guam</b>	0.4 +/- 0.6 cm/decade (0.1 +/- 0.2 in/decade)	1948Ð 2000	2.0 +/- 3.2 cm (0.8 +/- 1.3 inches)
<b>American Samoa</b>			
Pago Pago	1.6 +/- 0.5 cm/decade (0.6 +/- 0.2 in/decade)	1948Ð 2000	8.5 +/- 2.7 cm (3.4 +/- 1.0 inches)
<b>RMI</b>			
Majuro	2.8 +/- 1.0 cm/decade (1.1 +/- 0.4 in/decade)	1968Ð 2000	9.2 +/- 3.3 cm (3.6 +/- 1.3 inches)
Kwajalein	1.1 +/- 0.4 cm/decade (0.4 +/- 0.2 in/decade)	1946Ð 2000	5.9 +/- 2.2 cm (2.3 +/- 0.9 inches)
Wake	2.0 +/- 0.5 cm/decade (0.8 +/- 0.2 in/decade)	1950Ð 2000	10.3 +/- 2.6 cm (4.1 +/- 1.0 inches)
<b>FSM</b>			
Pohnpei	2.8 +/- 1.9 cm/decade (1.1 +/- 0.7 in/decade)	1974Ð 2000	7.5 +/- 5.1 cm (3.0 +/- 2.0 inches)
Kapingamarangi	-1.6 +/- 2.3 cm/decade (-0.6 +/- 0.9 in/decade)	1978Ð 2000	-3.7 +/- 5.3 cm (-1.5 +/- 2.1 inches)
Yap	-1.1 +/- 1.8 cm/decade (-0.4 +/- 0.7 in/decade)	1969Ð 2000	-3.5 +/- 5.8 cm (-1.4 +/- 2.3 inches)
<b>Palau</b>			
Malakal	0.2 +/- 1.8 cm/decade (0.1 +/- 0.7 in/decade)	1969Ð 2000	0.6 +/- 5.8 cm (0.3 +/- 2.3 inches)

Original data for this table provided by Mark Merrifield, University of Hawaiʻi (Merrifield, 2000).





# CHAPTER THREE— CHALLENGES AND OPPORTUNITIES

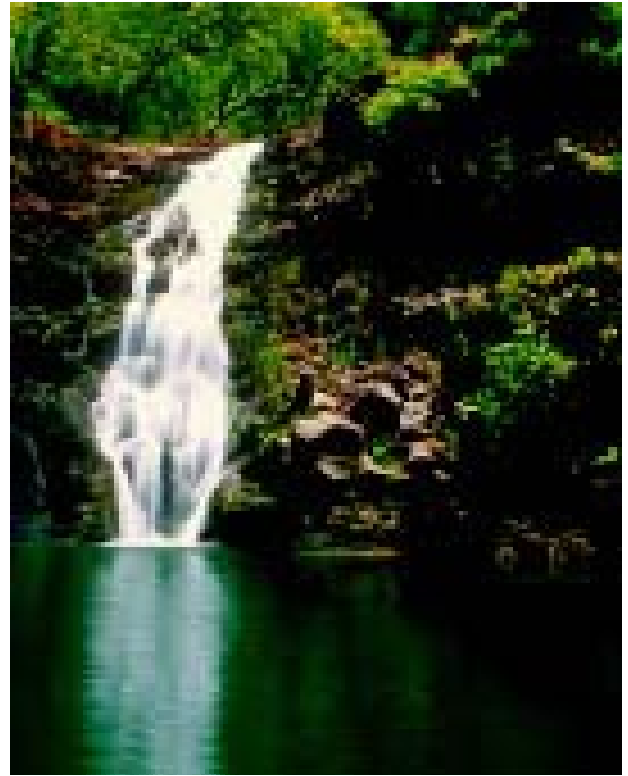
The Pacific Assessment encouraged and supported exploration of climate vulnerability in the context of six activities:

- Providing access to fresh water;
- Protecting public health;
- Ensuring public safety in extreme events and protecting community infrastructure;
- Sustaining agriculture;
- Sustaining tourism; and,
- Promoting wise use of marine and coastal resources.

These activities were identified in discussions at the 1998 Workshop and subsequent meetings of the steering and organizing committees, and chosen based on their sensitivity to climate, their role in maintaining the well being of island communities, and/or the special values attributed to the activities by island people. Also explored during the Assessment were the linkages and interactions among these activities, and the extent to which interdependencies might ameliorate or exacerbate vulnerability to climate change and variability. The following sections summarize insights into climate-related vulnerability in the Pacific Islands; these insights emerged from the March 1998 and November 2000 Pacific Assessment Workshops, as well as individual small-group discussions with representatives of key stakeholder groups, and from analytical studies that supported the Assessment.

## Providing Access to Fresh Water

As one participant in the March 1998 Workshop noted, “Water is gold.” Water’s value is even greater in island settings where surface water is limited if it exists at all, aquifers are small and fragile, and potable water may be available only from rooftop catchment systems. Given the precarious state of island hydrological systems, climate change or protracted anomalous conditions can have extreme effects on water supply. For example, during the 1982–83 ENSO warm event, Majuro’s reservoir held 6 million gallons (Mgal) on January 1. By January 17, the water had dropped to 4.8 Mgal. By May 1983, total storage had dwindled to 0.8 Mgal, most of which was being reserved for the hospital (Republic of the Marshall Islands, 1999).<sup>5</sup> Similarly, during the 1997–98 ENSO warm event, all islands in the North Pacific experienced a



*Evolution and geology have provided certain Pacific Islands with abundant sources of fresh water. Most, however, are not so bountifully endowed, and must manage their water with great care, especially in light of the growing impact of climate variability on this vital resource.*

rainfall deficit, and water managers were forced to ration municipal water supplies. The Marshall Islands again suffered the most extreme water shortages; at the height of the drought, municipal water on Majuro was only available for seven hours every fourteen days.

The problems of limited water supply are intensified by increasing demand for water. Population growth rates in some Pacific Islands are quite high. The Northern Marianas, for example, have an estimated annual population growth rate of 5.6%. The Marshall Islands are estimated to grow at a rate of 4.2% per year and American Samoa at 3.7% (SPC, 2000).<sup>6</sup> Further, domestic and international migration has contributed to the rapid

<sup>5</sup> Report from the Republic of the Marshall Islands presented at the Workshop on ENSO Impacts on Water Resources in the Pacific, held in Nadi, Fiji, October 19–23, 1999.

<sup>6</sup> Secretariat for the Pacific Community. 2000. “Selected Pacific Economies—A Statistical Summary”

growth of urban centers throughout the region. If the habitability of small islands and atolls is threatened by environmental change, migration to urban centers and high islands is likely to increase even more.

In addition to population pressure, economic development throughout the region also presents new demands on water resources. Tuna processing plants in American Samoa, for instance, require tremendous amounts of fresh water daily. Tourism, the premier industry in many island economies, is also water intensive. The island of Guam, for instance, had 8,119 hotel rooms in 1997, and the hotel occupancy rate for that year was 82% (Osman, 1999a).<sup>7</sup> This suggests that on any given day, Guam's water supply supported 6,650 visitors, roughly 4.4% of Guam's population in 1997.

Maintenance of golf courses, a popular tourist attraction, places additional pressure on precious local water resources. On several islands, disputes over access to limited water supplies have divided communities and entangled state agencies, private industries and citizens' groups in lengthy legal battles. On some islands, availability of water is the major problem, while on other islands, distribution is the focus of disputes. Long-standing institutional arrangements for managing water are challenged to adapt to the combined pressures of dwindling supplies and increasing demands. The search for alternative water supplies continues in earnest with research and development into desalinization projects such as reverse osmosis systems.

After the 1997–1998 ENSO warm event, the islands of Saipan, Majuro, Yap and Palau all made significant improvements in water storage and delivery systems. These initiatives have been complemented by efforts to reduce demand and promote efficient water use; new legislation in CNMI, for instance, imposes fines for wasting water. Water management institutions, whether based on traditional arrangements or administered by municipal, territorial or state agencies, have already benefited from climate information in their efforts to predict water supply and demand and allocate water supplies.

### *Findings and Recommendations*

Discussions during the Pacific Assessment reinforced the importance of addressing the adequacy and long-term stability of island water resources. They also highlighted the importance of effects on fresh-water resources as an underlying factor in determining the consequences of climate variability and change for most activities consid-

## **CLIMATE MODERATORS**

A number of Pacific Island characteristics influence the effects of climate on fresh-water resources, including:

- Island type, most notably the differences between “high islands” with greater groundwater and surface-water assets, and “low islands” with limited freshwater lenses and very little (if any) groundwater sources;
- Demographics, including population growth, overseas immigration and emigration, and internal migration into urban centers from smaller communities in more remote, low-lying islands and atolls;
- Remoteness, which is related to the population issues described above, and to distance from potential sources of fresh water during emergencies;
- Access to technology, including issues related to the ability to acquire new technology and maintain existing or new facilities;
- Economic activity, including reliance on water-intensive industries like tourism, agriculture and fisheries as dominant sources of national income; and,
- Social and cultural characteristics, including issues related to land tenure and resource management.

ered in the Assessment. During the November 2000 Workshop, for example, the importance of understanding climate-related changes in fresh-water resources was seen as particularly central to agriculture, including subsistence farming and fishing as well as cash crops; to fish processing and trans-shipment; to domestic use of water; to tourism and other commercial uses; to public health; and to maintenance of natural ecosystems. Exploring the implications of competition for this limited resource can be as important as understanding the effects of climate variability and change on any activity individually.

Along with these differences, Pacific Islands share a number of common characteristics that influence their ability to respond to the effects of climate variability and change on their fresh-water resources. For example, Pacific Islands share a general reliance on rain-fed sources of fresh water—whether groundwater, surface water or rainfall catchment systems—and this reliance on rainfall makes them particularly sensitive to climate extremes like prolonged droughts. Furthermore, a reliance on multiple sources of fresh water imposes a variety of requirements for water quality and treatment.

Pacific Islands are experiencing increasing development and population pressures, which are reflected in land use changes that affect water quality and quantity.

<sup>7</sup> Bank of Hawai'i. *Guam Economic Report*, October 1999.



*The Ahupuaʻa Resource Management System used in Hawaiʻi is a model of integrated management—it combines science with traditional Hawaiian knowledge and practices to optimize use and conservation of resources “from the mountains to the sea.”*

Storage capacity and water distribution systems in the islands are already stressed; while some improvements (like fixing leaks in distribution pipelines) may be relatively easy, major improvements to infrastructure will require substantial economic investments. On many islands, much of the water distribution infrastructure is old and needs to be replaced. It is estimated, for example, that water and wastewater improvements on Guam could exceed \$250 million. As is the case with all activities discussed during the Assessment, addressing these basic infrastructure concerns will be an important first step in improving the ability to cope with climate variability and change, as well as other stresses on water resources.

Discussions about how to enhance the resilience of Pacific Islands to climate-related stresses on fresh-water resources focused on responding in three categories: natural systems (surface and ground water, watersheds, wetlands, near-shore waters); human and institutional systems (including urban centers, rural communities, government agencies and regulatory regimes) and specific economic activities (e.g., agriculture, tourism, fish processing, domestic use/personal consumption). Table 3.1 summarizes key recommendations in each of these areas.

One of the common themes that emerged throughout the Pacific Assessment involved exploration of how traditional knowledge and practices can be applied to today’s climate-related problems and to planning for the future. In the case of fresh-water resources, this discussion focused on the specific example of the ahupuaʻa resource management system used by early Hawaiians. Ahupuaʻa, the ancient Hawaiian geopolitical land divisions, ran “from sea soil to

the mountainside or top,” providing the chiefs and the people all that was needed to thrive on the most remote archipelago on the planet. As one author describes:

*“A principle very largely obtaining in these divisions of territory was that a land should run from the sea to the mountains, thus affording to the chief and his people a fishery residence at the warm seaside, together with the products of the high lands, such as fuel, canoe timber, mountain birds, and the right of way to the same, and all the varied products of the intermediate land as might be suitable to the soil and climate of the different altitudes from sea soil to mountainside or top.” (Hawaiʻi Supreme Court, 1879)<sup>8</sup>*

The ahupuaʻa system evolved in a virtual fresh-water oasis in the largest saltwater desert on earth. It has survived for close to two thousand years while undergoing numerous changes and adaptations. A modern version, the Ahupuaʻa Resource Management System (ARMS), is receiving widespread attention today because of growing awareness that globalization and global warming pose serious threats to the fragile natural and cultural resources of Hawaiʻi. By integrating ancient wisdom and modern science, resource managers are finding that the ahupuaʻa system addresses such major challenges as watershed management, ecosystem restoration, integrated land and water-use planning, and integrated coastal zone management. Although consideration of the ARMS arose initially in discussions about fresh-water resources, this resource management approach also can be used to improve resilience in agriculture as well as coastal and marine resource management. Because the ahupuaʻa system is also a place-based economic system, it offers a framework for diversifying the economy of Hawaiʻi and other Pacific Islands, and opens up unlimited potential for workforce development as we seek adaptive strategies to meet the challenges of globalization and global warming.

One of the characteristics of the ARMS is the involvement of experts and stakeholders from all walks of life in discussions and decision-making. This concept of engaging multidisciplinary, multisectoral teams of experts in the development of effective adaptation strategies was a recurring theme throughout the Pacific Assessment.

<sup>8</sup> *Hawaiʻi Supreme Court. 1879. Re: Boundaries of Pulehunui, 4 Haw. 239, 241.*

Underlying such an approach is a fundamental requirement: the need to build trust and establish long-term, collaborative relationships among the diverse stakeholders. Participants in the Assessment recommended that the Pacific Assessment process be continued as a mechanism for establishing such partnerships through a sustained dialogue on the challenges and opportunities of climate variability and change.

## Protecting Public Health

Closely related to fresh-water resource issues are concerns about the consequences of climate variability and change for public health. Several recent initiatives aim to evaluate the effects of climate and extreme events on health. Though temperature extremes can have direct impacts on human health, and several reports attempt to draw direct relationships between climate and emotional health, it is climate's impact on pathogens and disease vectors that may pose the greatest threat to the most people. In Pacific Island communities, the impact of droughts on subsistence agriculture and food supplies can also pose a significant climate-related health risk.

A number of infectious diseases in Pacific Island communities are climate-sensitive, including dengue, leptospirosis, malaria, filariasis, cholera, Ross Valley fever, influenza and other upper respiratory infections, gastroenteritis and cryptosporidiosis. Increases in global travel and trade are increasing the risk that these and other infectious diseases may spread in Pacific Island communities.

Preliminary research on the relationship between climate variability and dengue fever (a mosquito-borne viral disease)

**Table 3.1. Enhancing the resilience of Pacific Islands to climate-related stresses on fresh-water resources**

<b>Natural Systems</b>	Protect and restore watersheds
	Conserve, recover and reuse water
	Integrate water- and land-use management
	Evaluate existing assets (from all systems) and develop unused/alternative sources
<b>Human and Institutional Systems</b>	Improve infrastructure and increase capacity
	Explore traditional and customary practices for water resource management to supplement/adjust existing management regimes (e.g., Ahupuaʻa Resource Management System in Hawaiʻi)
	Plan for the long term, emphasizing self-sufficiency
	Recover, treat and reuse wastewater
	Promote water conservation
	Review and revise permit and regulatory regimes to enhance resilience and reduce vulnerability to climate variability and change
	Use climate forecasts and information in decision-making; establish targeted climate information systems building on examples like PEAC
	Improve climate and water resource monitoring (including socioeconomic data)
	Address population and demographic issues
	Promote education and awareness
<b>Economic Activities</b>	Provide economic incentives for water conservation, recovery and reuse
	Plan for extremes (particularly droughts)
	Develop public/private partnerships especially among large-scale users (including the military)
	Develop businesses targeted at water resource management systems
	Use climate forecasts and information in decision-making
	Promote public awareness and conservation in hotels, restaurants and other gathering places
	Promote information exchange and dialogue

suggests that the risk of dengue fever may increase during dry periods in which a tropical storm or cyclone brings a brief period of heavy rainfall. It also appears that in some parts of the Pacific, the risk of dengue is higher during normal years and La Niña years than during El Niño years. Rainfall clearly has an impact on mosquito populations, and other research has shown that increases in temperature increase the risk of dengue outbreaks. Understanding these links between climate and dengue fever is important because, among vector-borne diseases, dengue is second only to malaria in numbers of people affected worldwide (Gubler et al., 2001). The relationship between climate variability and dengue fever, diarrheal disease, cholera, leptospirosis and ciguatera will be explored in a research



## REDUCING VULNERABILITY TO CLIMATE-RELATED HEALTH RISKS

- Improve hospitals and other healthcare facilities, especially infrastructure related to acute care
- Improve water resource and sanitation infrastructure
- Improve the communication of climate information to the health sector and enhance the capabilities of local meteorological services and climate research programs in the Pacific
- Enhance public health surveillance systems in the Pacific
- Enhance healthcare education and training programs
- Improve emergency services delivery systems
- Update and implement comprehensive emergency management programs that address preparedness as well as response
- Update and implement healthcare plans that emphasize preventative care
- Integrate existing climate information (e.g., ENSO forecasts) into healthcare and emergency-services planning on a regular basis
- Enhance efforts to integrate traditional knowledge and practices into discussions of climate and health, including the engagement of traditional leaders and teachers
- Integrate information on climate variability and change into planning and decision-making in key sectors, most notably water resource management and agriculture
- Pursue community planning and economic development programs that encourage a shift toward sustainability, particularly in water usage and agriculture
- Enhance education and training programs, including technical training for healthcare practitioners and climate scientists, as well as public awareness and outreach programs at the local level
- Improve the ways in which information about climate and health is provided, in part by adopting traditional language(s) to convey improved information about local climate and health conditions

project proposed for the Cook Islands, FSM and Fiji over the next three years (Hamnett and Lewis, personal communication).

Climate change affects ecological conditions that influence both human pathogens and the habitats of disease vectors. Climatic and environmental perturbations can create new conditions for infectious diseases. In the aftermath of Typhoon Nina, which struck in November of 1987, the Chuukese suffered an increase in amebiasis, a parasitic disease associated with fecally contaminated water (FEMA, 1992). Similarly, outbreaks of cholera may be associated

with climate variability and extreme events (Pascual et al, 2000). Cholera outbreaks can have severe consequences for any community. In calendar year 2000, FSM attributed 19 deaths and 709 hospital admissions in Pohnpei State to cholera.

Understanding the vulnerability of human populations to climate-sensitive diseases and disease vectors is improved by the use of models that integrate epidemiological methods with models of complex systems dynamics. For instance, Martens (1999) suggests that, based on “first generation” models of complex interactions, malaria and dengue will enjoy warmer environments, while temperature increases would be less conducive to schistosomiasis. Such findings are even more useful when they incorporate sociocultural variables that may provide information about the distribution of vulnerability within populations.

In addition to these vector-borne diseases, there are a number of synergistic relationships that increase the vulnerability of Pacific Island communities to climate variability and change. There is a strong relationship between both drought and flood and diarrheal diseases related to contamination of water supplies, although the exact nature of those impacts will differ from island to island (e.g., impacts on high islands with significant reservoirs of freshwater will be different than the impacts experienced on low islands with limited storage capacity). In this context, Assessment participants gave priority to understanding and addressing the health-related consequences of extreme events such as prolonged droughts, floods, or hurricanes and typhoons.

Another risk involves the potential for nutritional problems caused by the effects of climate on agriculture— most notably the effects of drought on subsistence crops and the effects of increasing ocean temperatures (and other climate-related changes) on subsistence fish species. In addition to enhancing the risk of a number of specific conditions such as anemia and low birth weight, malnutrition also tends to decrease the collective immunity of affected populations. In general it should be noted that geographic isolation, as well as social, economic and political inequalities, greatly exacerbate health problems and the delivery of healthcare.

Vulnerability to climate-related health risks is affected by sociocultural practices and beliefs as well. Certain behaviors (such as regular water treatment) or values (regarding health, well being and prevention) can be influential in reducing exposure. Public information campaigns are credited with reducing the incidence of diarrheal disease in Palau and Pohnpei during the 1997 ENSO-related drought (Hamnett, personal communication). Public health in

## FOCUS: INTEGRATION OF TRADITIONAL KNOWLEDGE AND PRACTICE

Regardless of the topic being discussed at gatherings for the Pacific Assessment, there emerged a strong call for the integration of traditional knowledge and practice into more contemporary methodologies of climate observations, research, assessment and response being considered for the region. This call was particularly clear in discussions of how Pacific Island communities might better adapt, or reduce their vulnerability, to climate variability and change. For example, in discussions about possible changes in coastal resource management, repeated emphasis was placed on the importance of evaluating historical experience through the prism of traditional practices, as well as through more recent, “western” management paradigms.

In this context, the oral histories of indigenous peoples were put forward as a valuable source of knowledge applicable in the context of climate assessment. The oral traditions of Native Hawaiians, for example, include the intergenerational transmission of ancient resource management practices encoded in stories (mo’olelo), chants (mele) and dance (hula). Demonstration of these multisensory expressions of ancient wisdom by contemporary practitioners is a powerful testament to their survival over time, and underscores the claim that traditional knowledge was intended to continue forever (a mau a mau). Such nonwritten forms of communication can be effective tools for public education that transcend not only generations, but also barriers of culture and language. Along these lines, it was recommended that more be done to enhance the historical record of climate events and adaptations by integrating oral histories with observations of climate from instrumented records.

Furthermore, traditional leaders and teachers were identified as critical sources of insights into the vulnerability of Pacific Island communities to climate variability and change, and as important actors in the development and implementation of adaptation and mitigation strategies. The importance of engaging these traditional experts was highlighted in discussions about adapting the Hawaiian institution of an ‘aha council, in which all affected parties work to resolve resource management concerns through sustained dialogue and shared decision-making.

Traditional leaders and teachers were also identified as important information brokers in Pacific Island communities, with a vital role to play in increasing public awareness of the challenges and opportunities of climate variability and change. In this role, these leaders could facilitate the development and acceptance of effective response options that respect cultural considerations, as well as economic and environmental ones. Discussions of public education and awareness furthermore emphasized the valuable role that local experts can play in presenting climate information in local languages.

Another process considered appropriate for infusion of traditional knowledge and practice was implementation of long-term, proactive approaches to climate adaptation, a common theme that emerged throughout the Assessment. For example, in early discussions of how best to sustain agriculture, participants recommended embracing the concept of *meninkairoir* – a Carolinian word that means “looking ahead” or “taking the long view.”

Yet others expressed serious interest in an ahupua’a approach to watershed and resource management, providing another strong example of the value to many of exploring traditional approaches to resource management. Such place-based, historical interpretations of the environment can significantly enrich contemporary understanding of the local consequences of climate variability and change. In addition, when we develop a better appreciation for how early Hawaiians and other indigenous peoples used their comprehension of climate to support decision-making, we gain valuable insights into how we might better integrate climate observations and information into our daily decisions.

For example, during the November 2000 “Workshop on Climate and Island Coastal Communities,” Kumu Hula John Ka’imikaua spoke of the importance of people becoming more aware of the environment around them by using their senses and na’au (gut instinct, or intuition), as well as their intellect, to understand their relationship to the climate system. To illustrate, Ka’imikaua described how early Hawaiians characterized the many types of winds on Moloka’i in terms of direction, strength, scent or feel; he added that each of these descriptions conveyed an understanding of important corresponding conditions such as the availability of certain fish in coastal waters, or the timeliness of planting certain crops.

In her 1992 book *“La’au Hawai’i, Traditional Hawaiian Uses of Plants,”* Isabella Abbott noted, for example, “Early western observers were impressed with the bounty that the Hawaiians took from the land and the expertise they showed in manipulating their crops. Hawaiian understanding of their plants and the handling of plant varieties to suit the different ecological niches available on each island enabled them to reap an abundant harvest from limited cropland with considerable certainty.”

By exploring traditional knowledge, people and institutions in the Pacific today can perhaps relearn the value of greater personal intimacy with the environment that sustains us— and thereby respond more holistically to the cues it continuously provides.

general is supported by the direct intervention of health-care providers, whether they are traditional healers, medical professionals, public health officials or international aid workers. Through various organizational and institutional arrangements, these healthcare providers may be respon-

sible for designing and implementing programmatic responses to public health problems. These projects are likely to be enhanced by the use of climate information.

### *Findings and Recommendations*

The current state of public health in the Pacific Islands is sensitive to climate variability and change largely through climate-related effects on infectious diseases, fresh-water resources and food supplies. The following characteristics of healthcare, demographics and socioeconomic conditions in the Pacific Islands affect the region's vulnerability to climate:

- variations in availability of and access to healthcare facilities, especially for communities in remote outer islands;
- a high proportion of substandard facilities;
- a general shortage of doctors, healthcare providers and medicine;
- variations in cultural acceptability (and hence use) of healthcare facilities;
- remoteness from emergency response providers;
- vulnerability to epidemics and diseases introduced to the islands through movement of goods and services from other places;
- high population growth rates in some islands (e.g., the Republic of the Marshall Islands) with consequent implications for limited island resources;
- varying and interrelated status of socioeconomic development, poverty, nutritional status and sanitary conditions; and,
- varying levels of education, including health and environmental education.

It is important to note that climate variability and change impose added pressures on a public health infrastructure that is already stressed in many Pacific Island jurisdictions.

While the entire population of island communities is exposed to public health risks associated with climate variability and change, there are a number of groups that are particularly vulnerable, including the elderly and the very young; individuals with limited access to resources; rural communities with limited water storage, drainage and sanitation; and communities with limited access to immunizations and general health support.

Current understanding of the effects of climate variability and change on health in the Pacific (and globally) is constrained by a number of factors; these include:

- limitations on the availability and quality of climate data, and access to it, on a scale (resolution) compatible with health studies, as well as the absence of healthcare statistics and information on local or subnational scales;
- limited research on specific climate-health connections, such as multidisciplinary case studies that explore the potential for effective use of climate forecasts and information to reduce health risks in the Pacific;

- the need to develop new methodological approaches, as current statistical methods and modeling techniques do not always work for climate and health studies;
- the absence of focused exploration and integration of indigenous knowledge and practices into response options; and,
- the absence of information and research on synergistic relationships like that between public health and the effect of climate on agriculture and water resources.

As a result, one of the principal recommendations that emerged from the Assessment was that support be increased for scientific efforts to address these factors. In thinking about additional ways to reduce the vulnerability of Pacific Island communities, a number of actions were recommended to strengthen infrastructure and enhance the capabilities of the communities.

In all cases, participants in the Pacific Assessment recommended building on the capabilities of existing institutions and programs such as the Pacific Islands Health Officers Association (PIHOA); health surveillance programs through the Pacific Community and similar programs of the WHO; the national meteorological and hydrological services, and the PEAC as a critical first step.

Furthermore, participants in the Assessment encouraged collaboration between sectors and communities within individual jurisdictions, as well as among Pacific Island nations in the pursuit of these recommended actions. Cooperation between islands and among island communities, for example, could prove useful in leveraging resources such as investments in disease control infrastructure and drugs. Similarly, participants emphasized the importance of ensuring that individual government agencies provide a consistent message regarding climate and health conditions. As noted earlier, climate variability and change may increase or decrease the likelihood of a given infectious disease but there are many other factors involved, including human behavior. As a result, underlying all of the recommendations that emerged from the Assessment was a call for continuous dialogue and enhanced cooperation among healthcare officials and practitioners, scientists, governments, businesses and community leaders, as part of a regional effort to understand and address the consequences of climate variability and change for Pacific Islands.



*Extreme events such as tropical storms can have a dramatic effect on lives, property and ecosystems in the Pacific Islands; these consequences make clear the importance of collaborative efforts to reduce vulnerability to such events.*

## Ensuring Public Safety in Extreme Events and Protecting Community Infrastructure

Island coastal communities have a long history of weathering extreme events. Typhoons, heavy winds, torrential downpours, tidal surges and floods have taught past generations about the sheer force of nature. Buildings are collapsed, trees are uprooted and airborne debris becomes lethal projectiles. Unfortunate souls caught in powerful storms can be injured or even killed. In December 1997, Typhoon Paka hit Guam with sustained winds of 150–160 mph. At least 17 injuries were reported and scores of homes were destroyed. FEMA provided more than \$109 million of recovery assistance, but total damages on Guam exceeded \$600 million (Guard, 2001, personal communication). Following Typhoon Paka, Guam enhanced enforcement of building standards (among the strongest in the U.S.) and changed insurability standards.

Though there are few major rivers in the region, flash floods can be swift and deadly. The likelihood of extreme flooding and mudslides is increased dramatically when deforestation leaves the already fragile island soils even more vulnerable to the effects of heavy rains. The incidence of coastal inundation is expected to increase in the islands in coming years, with variations in sea level experienced as both extreme events and gradual encroachment on coastal areas.

On the other end of the hydrological extreme, droughts can pose threats to public safety, for instance, by increasing the risk of wildfires. Smoke from these fires not only leads to respiratory ailments and skin and eye irritations, it also dramatically reduces visibility and has been blamed for

plane crashes, boating accidents, and uncounted motor vehicle fatalities.

The tragedy of extreme climatological events is softened only by foresight and preparedness in vulnerable communities. All of the U.S.-affiliated islands have some official agency responsible for preparedness, and for response to damage from extreme events. Emergency management and civil defense agencies develop disaster response plans and conduct public information campaigns. And the National Weather Service, thanks to advances in meteorological monitoring and prediction, can give advance warning of tropical storm events. Unfortunately, responsibility for mitigation is spread among several agencies and is not as well organized as preparedness and response. The built environment, whether concrete and steel or bamboo and pandanus, is susceptible to the forces of nature. Since World War II, government and the private sector have made a tremendous investment in homes, public buildings and tourism facilities. In many areas, however, current building standards leave buildings and infrastructure vulnerable to high winds, flooding and coastal erosion. In this situation, if the frequency and severity of extreme events increase, greater losses can be expected in the future.

In Hawai'i, the Army Corps of Engineers conducted a survey of the vulnerability of energy and lifeline facilities to hurricanes or tsunamis (Army Corps of Engineers, 1992). They found that numerous electrical power plants and substations were located within coastal inundation zones. Similarly, petroleum and gas storage facilities are mostly located at sea level, within the commercial harbor areas of all the Hawaiian Islands. Kaua'i's experience during Hurricane Iniki provides a compelling example of the importance of reducing the vulnerability of energy systems; the disruption of Kaua'i's electrical system by Iniki shut down operation of the island's water distribution system even though water was available. The situation on the island of Lana'i is particularly instructive because, although its terminal facilities are not subject to flooding, storm damage to the breakwater allows waves to enter the harbor, thus preventing fuel barges from entering to off-load fuel; similar scenarios might be envisioned for other critical shipments.

Also at risk are lifeline facilities, including communications, telephone offices, fire and police stations and wastewater facilities, thus exacerbating the potential threats to public health and safety already associated with extreme events (such as hurricanes and storm surge), as well as the potential long-term implications of sea-level rise.



**Table 3.2. Vulnerability to Climate-Related Natural Hazards in Selected Pacific Islands**

Country	Cyclones, Hurricanes, Typhoons	Coastal Flooding (Sea-level variability)	Mud and Landslides (heavy rains/ floods)	River Flooding (heavy rains/ floods)	Drought
<b>FSM</b>	Medium	Medium	Medium*	Medium	High
<b>RMI</b>	Low	High	Low	Not Applicable	High
<b>Republic of Palau</b>	Medium	Medium	Low**	Low** (Not applicable)	MediumÐ High (Medium)
<b>American Samoa</b>	High	Medium	Medium	Low	Medium
<b>Guam</b>	High	Medium	Low	Medium	MediumÐ High
<b>CNMI</b>	High	Medium	Low	Low	High
<b>HawaiÔ i</b>	Medium	Medium	Medium	High	MediumÐ High

*Source: adapted from a table in Natural Disaster Reduction in Pacific Island Countries: Report to the World Conference on Natural Disaster Reduction, 1994, Section 2.2, p.9.*

Vulnerability estimates for American Samoa, Guam, the Northern Mariana Islands and HawaiÔ i have been added; non-U.S.-affiliated states were not included in the original 1994 report.

Identification of a range of estimates indicates that the views of participants in the Assessment differed from the authors of the original table; estimates from the original table are provided in parentheses.

*\*FSM's vulnerability to mudslides was raised from low to medium based on mudslides on Chuuk during Typhoon Pamela, mudslides on Pohnpei in 1997, and the practice of planting sakau (kava) at higher elevations.*

*\*\*Palau's vulnerability to both mudslides and flooding may change as Babeldaob, the second largest island in Palau, is developed.*

### *Findings and Recommendations*

In considering the challenges of ensuring public safety and protecting community infrastructure, a number of climate-related hazards of concern were identified, including droughts; fires (as a secondary hazard often associated with drought conditions); typhoons, hurricanes and severe cyclones (with wind, wave, and rain/flooding hazards); floods and heavy rains (with mud and landslide hazards); episodic high surf conditions; sea-level variation (on various time scales) and long-term sea-level rise (with coastal inundation hazards). Table 3.2 provides estimates of the current vulnerability of Pacific Island jurisdictions to some of these hazards.

ENSO events play a critical role in this region, so participants in Assessment discussions about ensuring public safety and protecting community infrastructure decided to focus specifically on four possible futures: (1) continuation of the current pattern of El Niño events (dry one year and wet the following year); (2) more frequent or “persistent” El Niño (dry) conditions; (3) more frequent heavy rain/

monsoon-like events; and (4) an increase in temperature and general intensification of the hydrological cycle. Table 3.3 provides a summary of how those four potential conditions might affect the climate-related hazards of concern to those charged with ensuring public safety and protecting community infrastructure.

Setting these possible future scenarios in the context of existing experiences, the following conclusions were drawn about the capacity of Pacific Island jurisdictions to respond to the public safety challenges of climate variability and change:

- The capability of Pacific Islands to cope with climate-related hazards and natural disasters is already limited.
- There is great dependence on outside assistance during disasters, and this dependence increases with the severity of an event.
- Recovery from severe disasters is slow and difficult.
- Should the frequency and/or intensity of individual extreme events increase, islands may be less able to absorb and recover from disasters.

**Table 3.3. Effects of Climate Scenarios on Public Safety Hazards**

<b>Climate-related Hazard or Event</b>	<b>Status Quo (current patterns of El Niño)</b>	<b>More Frequent or "Persistent" El Niños</b>	<b>More Frequent Heavy Rains (monsoon-like events)</b>	<b>Temperature Increase; Enhanced Hydrological Cycle</b>
<b>Drought</b>	On large scale during strong El Niño	More west of dateline; Less in equatorial regions east of dateline	Between El Niño years	Wet areas wetter; dry areas drier; small change overall
<b>Floods / Heavy Rains</b>	Highly variable; can be El Niño-related	Highly variable during wet years; fewer in dry years	Increase in floods, erosion, mudslides and landslides	Wet areas wetter; dry areas drier; small change overall
<b>Tropical Cyclones, Hurricanes, Typhoons</b>	Highly-variable; can be El Niño-related	Shift toward dateline and Central Pacific; possibly more intense	Little or uncertain effect on intensity or frequency	Relatively small change in intensity; may be higher frequency
<b>Sea-level Variability and Change</b>	Multi-year, El Niño-related variability	More episodes of low sea level west of dateline and high sea level east of dateline	More frequent westerly winds and accompanying coastal flooding	Slow sea-level rise; by itself significant over the long term
<b>Fires</b>	During El Niño, west of dateline; otherwise poleward of 10° west of dateline	More fires west of dateline	Little change and possibly a decrease	More in dry areas; less in wet areas

- Resource-restricted islands find it particularly difficult to absorb a series or combination of disasters, and it is not clear how or under what conditions emergency response and recovery systems might reach a breaking point.
- There are significant differences within the region in the expected impacts of future climate scenarios, and in the capabilities of specific jurisdictions to respond to those impacts.
- While information on standard adaptive techniques such as setbacks, seawalls and flood-reduction measures is fairly readily available, care should be taken to ensure that designs are appropriate to specific jurisdictions, and that the impacts of those response options on other aspects of a community's vulnerability are assessed; and,
- Appropriate responses depend on a better understanding of current conditions and on development of more reliable climate scenarios and site-specific information.

Underlying specific recommendations for enhancing the adaptive capacity of Pacific Island jurisdictions was a call to move from today's more reactive disaster-response systems to systems that are more anticipatory, encompassing disaster prevention and preparedness as well as emergency response, recovery and mitigation. Such a proactive

approach was viewed as the most economical over the long term, and would also produce near-term benefits to individual jurisdictions and the region as a whole. Similarly, implementing incremental, near-term adaptive measures that respond to today's patterns of natural variability (most notably ENSO events) can result in near-term savings and provide valuable insights into designing strategies for effective response to long-term climate change. Iterative, incremental changes represent a more likely scenario for adaptation to climate change than large, instantaneous changes.

Other recommendations were also made to enhance the ability of Pacific Islands to ensure public safety and protect infrastructure in the face of climate variability and change; these include:

- Improve efforts to monitor and predict climate conditions and changes.
- Integrate existing information about climate variability and change (e.g., ENSO forecasts) into emergency preparedness planning.
- Continuously monitor sea-level changes and use data to evaluate inundation and flooding maps and planning assumptions.

- Shift to more sustainable systems of water usage and agriculture.
- Integrate disaster management policies and enhance the flow of information across all levels of government by creating interagency, cross-jurisdictional bodies such as the government-wide task forces established in a number of Pacific Island jurisdictions to respond to the 1997–1998 El Niño event.
- Conduct island- and country-level assessments of climate-related vulnerabilities, and identify priorities for response options.
- Develop and/or update island and multihazard national emergency management plans.
- Embed emergency preparedness and response needs in a sustainable development planning context designed to improve environmental, educational, public health and living standards, as well as to promote economic development.
- Implement and enforce existing hazard mitigation measures and policies.
- Increase integration of traditional knowledge, adaptation strategies and cultural practices into contemporary disaster management strategy.
- Take greater advantage of new technologies like laser mapping techniques and computer-assisted decision-support systems like GIS and visualization tools.
- Improve ties between scientists and decision-makers.
- Strengthen education and outreach programs that are responsive to local needs, and broaden public awareness and involvement in decision-making.

From the perspective of ensuring public safety and protecting community infrastructure, nearly all island communities, systems and activities are affected by climate variability and change. However, it was agreed that effects on fresh-water quality and availability are particularly

**Table 3.4. Examples of Climate Effects on Pacific Island Agricultural Systems**

<b>Drought</b>	Irrigated agriculture in Hawai'i is at risk from drought because of dependence on surface water
	Dryland, rain-fed agriculture on some high islands is at risk from severe droughts (often associated with El Niño)
	Some atolls near the equator are subject to droughts that have resulted in loss of trees and other crops
	Mangrove forests on some islands have experienced die-back that may be related to drought-induced stress
<b>Erosion/ Saltwater contamination</b>	Taro pits on some islands and atolls in the FSM, RMI and Palau have been contaminated by salt water associated with a depletion of fresh-water lenses, extended droughts and saltwater inundation/intrusion
	Some islands have experienced erosion in coastal areas and this has increased the risk of saltwater inundation into low-lying agricultural areas
<b>Plant disease/ Insect pests</b>	Taro blights and leaf-rot in some island areas may be the result of droughts and other environmental stresses
	There has been an increased threat of insect pests as a result of droughts, particularly white flies that affect breadfruit and other crops
<b>Invasive species</b>	Important island ecosystems have been stressed by droughts as well as alien invasive species; disturbances such as storms and extended droughts can often favor invasive species over indigenous species
<b>Wildfire</b>	Wildfires are a major problem during severe droughts in some jurisdictions

critical over the near and long term, and should receive priority in efforts to reduce vulnerability. As a result, immediate repair of infrastructure problems was strongly encouraged, as was local assessment of available water resources (including surface, groundwater and rainfall catchment systems) and water storage and distribution systems.

## Sustaining Commercial and Subsistence Agriculture

Agriculture, both commercial and subsistence, remains an important part of the economies of many of the islands addressed in this Assessment. Climate-related changes in rainfall and tropical storm patterns present problems for agriculture in island communities, as evidenced by the effects of the 1997–1998 El Niño event in the Pacific. Agriculture throughout the U.S.-affiliated Pacific Islands in 1997 and 1998 suffered from the droughts, except on Guam. There, farmers used public water for irrigation, and the delay of heavy rains toward the end of the drought



*Commercial and subsistence farming in the Pacific Islands are subject to the same climate-induced problems, including drought and salinization of fresh-water sources due to sea-level rise.*

resulted in one of the most productive harvests in recent history. In the CNMI, citrus and garden crops were most affected, forcing the local hospital to buy imported fruits and vegetables. On Pohnpei, serious losses of both food and cash crops were sustained, with significant stress evident in more than half the banana trees, and significant losses in the kava (sakau) crops (Hamnett, Anderson and Guard, 2000).

The greatest percentage of the most productive agricultural land on these islands is located in low-lying coastal areas that are at risk from climate-related changes in sea level. In addition to problems associated with inundation, saltwater intrusion caused by sea-level rise would also present challenges unless salt-tolerant species could be utilized.

Agriculture in the Pacific Islands is characterized by heterogeneity, which results from differences in local climatic, soil and hydrologic conditions, and from variations in the mix of subsistence and cash crops. Interisland differences can be seen in:

- the cultural context for agriculture;
- economic and market conditions such as proximity to markets and the availability of transportation;
- the relationship of agriculture to other relevant sectors, such as water and energy; and,
- the institutions that set and implement agricultural policy, as well as those that support research and develop and disseminate information such as weather and climate forecasts.

This heterogeneity highlights the importance of research and assessment that focuses on local conditions, institutions and cultures when considering climate-related

vulnerabilities in agriculture, including the development of response options. This report provides some regional insights and general guidelines that could be useful in pursuing such local efforts. For example, the Ahupua'a Resource Management System (ARMS) described earlier in this chapter represents a place-based approach that integrates local variability in climate and resources.

### *Findings and Recommendations*

Two categories of vulnerability were identified for the agricultural sector; the first includes vulnerabilities related to the physical environment, including climate-related risks, and the second includes social, political and institutional practices. As is the case with all activities addressed in the Assessment, the most critical of these risks are extreme events that can have severe impacts on local and regional agricultural production.

Droughts, for example, can reduce yields, with specific impacts dependent on characteristics such as duration and timing. Storms can affect agriculture in a number of ways, including crop damage from high winds and/or flooding, as well as degradation of soil quality and crop damage from sea-water inundation caused by storm surge. Natural climate variability, even when it is not manifested in the form of extreme events, poses a variety of challenges to the agricultural sector. Most notable is variation in the timing and amount of rainfall available for crop production. Agriculture on Pacific Islands is also affected by a number of pests (plant, animal, fungal and microbial) that can have a range of effects on crop production and are particularly important in areas with little crop diversity. Table 3.4 summarizes some of the effects of climate on Pacific Island agricultural systems.

Finally, agriculture must compete with a number of other uses for limited fresh-water resources. In their August 2000 decision on the Wai'ahole Ditch case, for example, the Hawai'i Supreme Court used the Public Trust Doctrine to outline a hierarchy of uses for water distribution during shortages. Maintenance of trust resources, including public health, safety and cultural practices, was held to be paramount, with private sector interests such as agriculture bearing the burden of proof that their uses would not cause irreparable harm to the trust. Like pests, fresh-water resources themselves are affected by climate variability and change.

Island governments and citizens are encouraged to develop more resilient agricultural systems that are less susceptible to damage from storms, drought and salt-water contamination. Specific actions in this context include planting of





*A traditional staple food in the Pacific Islands, taro (kalo) is often grown in coastal plots that are susceptible to climate-related problems such as saltwater contamination. Possible solutions to this vulnerability include elevating plots and developing salt-resistant varieties.*

traditional famine foods and food-banking crops used as famine foods; introduction of drought- and salt-resistant crops; development of emergency preparedness and disaster management plans that minimize disruptions to agricultural production; and shifting away from monoculture to greater diversity in crop production. Conversion of forest land to mono-crop agriculture and pasture, and shifts in low-lying areas to mono-crops such as sakau (kava), were identified as examples of current trends that may be increasing the vulnerability of Pacific Island agriculture to climate variability and change. More diverse agricultural systems would provide an important buffer against disasters, and increase economic resilience in the face of major disruptions to single crops. As a result, diversification was advocated as a general strategy to make agricultural systems less vulnerable. Traditional practices such as the Ahupua'a Resource Management System can provide insights into approaches that use diversification to enhance individual communities' self-sufficiency and resilience to climate variability and change. This is because the ARMS approach encourages development of agriculture that is in concert with the soils and climate within "micro-regions" as small as individual valleys on single islands.

Addressing climate variability and change in the context of comprehensive emergency management plans could reduce the effects of extreme events on Pacific Island agriculture. For example, the new drought mitigation and response plan in Hawai'i may make agriculture and ranching in the state less vulnerable to droughts—so encouragement was given throughout the Assessment to consideration of similar plans and programs in other island jurisdictions.

Adaptations to the problem of saltwater contamination of taro patches already have been developed in some areas,

and these techniques should be shared; they include construction of elevated (above ground) taro patches made of coral rubble or concrete and filled with soil and compost; shifts on some islands to dry-land taro; and planting drought- and salt-resistant varieties of taro.

In the second category of agricultural vulnerabilities (social, political and institutional practices), one of the most critical issues is a significant information gap between those who produce information about climate risks and those who use (or could use) that information to make decisions in the agricultural sector. It was noted that scientists, governments, businesses and community leaders could narrow this

information gap by enhancing awareness of available climate information; by improving the scientific community's understanding of decision-makers' information needs; by improving the usefulness and usability of climate information that addresses specific needs; by establishing and sustaining enhanced trust and credibility in forecasts, assessments and other information products; and by providing sufficient resources to support both science and a sustained dialogue between scientists and decision-makers.

Participants in the Pacific Assessment also repeatedly and strongly encouraged the development, provision and use of improved climate information, and highlighted two examples of institutions working to reduce the information gap. One was the PEAC, whose work during the 1997–1998 El Niño was described in Chapter 2. The second was Land Grant Colleges in the Pacific Islands, which help governments and farmers minimize the effects of extreme events and recover more quickly from natural disasters. An example of this assistance from the Land Grant Colleges is their cultivation of disease-resistant varieties of crops and tissue cultures, used to produce planting materials following a disaster; continuation and enhancement of such efforts was encouraged.

Also noted is the frequent mismatch between the timescale of climate events and that of political and individual decision-making. The need for policymakers to respond quickly to current problems can make it difficult to engage them in discussions of potential future problems, such as climate change. It was noted that there is a problematic tendency toward reactive decision-making instead of proactive planning, and that long-term, strategic approaches to problems of climate variability and change

should be developed. The Carolinian word “meninkairoir”<sup>9</sup>— which means “looking ahead” or “taking the long view”— captures the essence of this management strategy, which considers the long-term sustainability of agriculture and provides greater flexibility to respond to extreme events and potential surprises in the climate system.

Land use management policies and practices were identified as another contributor to vulnerability in Pacific Island agriculture. There is tension between the need for government regulation of land use to minimize potential climate-related threats, and the prerogatives of individual property rights and traditional land tenure systems. In some cases, climate-related threats, particularly those associated with extreme events, may require regulation of land use practices. An over-exploitation of limited land resources and degradation of terrestrial and coastal ecosystems could be associated with the trend toward increased commercialization of agriculture and globalization of agricultural industries, for example. These conditions can increase the vulnerability of Pacific Island communities to the risks of climate variability and extreme events. Addressing increasing erosion problems may require changes in land use policies. Also needed are enhanced policies and procedures to stop the introduction of alien invasive species, so as to reduce the threat to native ecosystems and agricultural systems— a threat that may increase following extreme events and other disturbances, when invasive species often have a competitive advantage.

Another institutional aspect of reducing the climate-related vulnerability of Pacific Island agriculture involves the need for greater cooperation across levels of government and among various interests. Given the multi-scale nature of agriculture (from global markets to individual producers and consumers) and the multi-scale nature of climate phenomena (from global processes to local effects), coordination across different levels of government (from international to local) is necessary. Greater coordination would minimize inconsistency in decision-making at different government levels, which sometimes results in issuance of conflicting incentives. An example is a national farm policy that provides incentives for local farmers to grow crops that are inappropriate given the constraints on that area's water resources. Similarly, coordination among different agencies and interests would facilitate understanding of the links between different issues, such as hydrological processes and soil quality; this in turn would lead to more consistent decision-making (e.g., water and energy policies that are consistent with agricultural policies and vice-versa).



*Beautiful beaches and weather are among the Pacific Island characteristics that drive tourism, yet both are already subject to stress from pollution and growing coastal populations. Climate change could generate additional risks for the industry by causing sea-level rise and compromising fresh-water supplies.*

## Sustaining Tourism

Tourism remains a significant contributor to the economies of Hawai'i, Guam and the CNMI, and is considered to offer economic growth potential for most of the jurisdictions addressed in the Assessment. Unique terrestrial and marine ecosystems are among the natural assets that draw tourists to the islands of the Pacific. These natural assets are already under stress from pollution and the growing demands of an increasingly coastal population. Sea-level rise associated with climate change could exacerbate those stresses in a number of ways: by reducing the extent and quality of sandy beaches through both inundation and storm-surge erosion; by inundating low-lying areas and threatening key infrastructure, including airports and roads; by increasing the risks of tropical storm damage (particularly damage associated with storm surge); and by threatening coastal water supplies through intrusion of salt water into the fresh-water lenses of small, low-lying islands.

Other climate-related changes of concern to tourism

<sup>9</sup> The potential value of the concept of meninkairoir to reducing vulnerability to climate variability and change was initially offered by Salvatore Iriarte (FSM) during discussions of climate and agriculture at the March 1998 Workshop on the Consequences of Climate Variability and Change for Hawai'i and the Pacific.



*Irrigation for golf courses and resorts is one among the many demands tourism places upon limited fresh-water resources in the Pacific Islands; growing populations, agriculture and processing industries are other elements that must be balanced in the complex task of water management.*

include:

- changes in rainfall patterns, particularly those that might bring more frequent and/or severe drought conditions, thus affecting the adequacy of water resources that support this water-intensive sector;
- changes in tropical storm patterns, which would have direct consequences for facilities and infrastructure and could exacerbate water-resource problems in certain areas;
- changes in temperature and rainfall patterns with attendant consequences for terrestrial as well as coastal and marine ecosystems; and,
- changes in ocean temperature, circulation and productivity, which could affect important marine resources like coral reefs and the fish they support.

### *Findings and Recommendations*

During the November 2000 Workshop, the tourism working group introduced its report to the closing plenary with the following statement: “Tourism is an extremely climate sensitive industry and should provide leadership to the larger community through its response to climate variability and change.” Examples of the sensitivity of tourism to climate, cited throughout the Assessment, include:

- the effects of ENSO-related drought on the availability of water for hotels and resorts, which often are located on the leeward (dry) side of islands;
- the vulnerability of the industry to hurricanes and typhoons, and the need for advance planning and preparation to protect visitors, as well as facilities and infrastructure; and,
- the dependence of the industry on marine and coastal resources like coral reefs, which in themselves are

climate-sensitive.

According to industry representatives, these examples illustrate how climate variability and change affect the foundation of a sustainable travel and tourism industry: ensuring safe, healthy conditions for visitors and providing adequate infrastructure to support their needs.

It was noted that the consequences of climate change for tourism could be both negative and positive. For example, increased intensity or persistence of El Niño conditions could lead to prolonged drought in many islands with adverse consequences for tourism. Climate-related changes in environmental conditions at alternative destinations could increase the number of visitors interested in traveling to Pacific Islands. Changes in climate-sensitive resources like coral reefs, fisheries and tropical forests could jeopardize the tourism business.

A change in sea level poses risks for transportation infrastructure like airports and roads, as well as hotels, restaurants and other facilities in coastal areas.

It was recognized that, to understand the vulnerability of tourism to climate variability and change, there should be discussions about response options as well as climate impacts. In this context, they noted that significant increases in the cost of diesel and airline fuels, which might arise as part of a global strategy to mitigate climate change, could reduce the number of visitors who choose to travel to Pacific Islands; nevertheless, they agreed that this possibility should not be used as an excuse to avoid consideration of important mitigation measures.

In the past, extreme events have galvanized public will and government and corporate action to reduce the sensitivity of tourism to climatic conditions. In Guam, for example, the losses associated with a Class 5 typhoon in 1962 helped pave the way for changes in building codes, for the imposition of a 20% tax for development in low-lying coastal areas, and for government subsidies and tax exemptions for developers who choose to build inland. Today, new insights and capabilities are generating opportunities to further reduce tourism’s sensitivity to climate; we know more about the relationship between the ENSO cycle and extreme events such as prolonged droughts or changes in hurricane and typhoon tracks, and we are better able to predict ENSO events months in advance. Taking advantage of such advances to reduce vulnerability to climate can also have near-term benefits for the industry. Clyde Mark (then-employed as a risk manager by Outrigger Hotels, Hawai‘i) cited the experience of the general manager of an Outrigger property in Australia, who used advance information about climate to anticipate and prepare for the conditions that

spawned a cyclone that caught other facilities unaware. As a result, guests at the Outrigger hotel were well-informed and prepared for the event, and hotel management had time to ensure that power and water supplies were maintained by acquiring additional generators and water purification systems (Mark, 2000, personal communication).

Discussions of the vulnerability of tourism to climate variability and change should take into account all stakeholders, including foreign and domestic visitors; employees and labor unions; hoteliers and restaurateurs; transportation operators (primarily planes and ships in the Pacific Islands); activity owners and operators; government and industry policymakers and planners (including agencies responsible for water, energy, transportation, communications, sanitation, economic development and emergency management); convention and visitors bureaus; chambers of commerce; tourism industry associations; developers and construction businesses; scientists; and the community at large. To make this process manageable, the Assessment suggests that discussions should be organized around three basic systems: community infrastructure; natural resources and ecosystems; and governance systems.

In the area of community infrastructure, the recommended focus would be improving resilience to climate-related extreme events. For tourism, the overarching goal would be to improve the ability of Pacific Island communities to adapt to the ENSO and other aspects of year-to-year climate variability, and to integrate considerations of climate change into long-term facilities planning. The 1999 FSM National Communication to the United Nations Framework Convention on Climate Change notes that “the tourism sector can place significant demands on water resources and supporting infrastructure” (FSM, 1999). Of particular interest to tourism would be reducing climate-related vulnerability in water resources, sanitation, public health and safety, transportation, energy, communications, visitor accommodations, and sports and recreational activities.

It was recognized that the tourism industry depends on the health of the islands’ natural resources, most notably their coral reefs, forest ecosystems and beaches. The FSM 1999 National Communication notes that “many tourism opportunities involve capitalizing on marine and coastal resources and, therefore, are likely to place demands on coastal areas and infrastructure already under pressure” (FSM, 1999). The industry, therefore, has a responsibility to consider the effects of climate variability and change not only on its own businesses, but also on the natural systems that sustain it. Detailed

discussions of the vulnerability of these systems are provided later in this chapter. As noted earlier, however, these critical natural resources are already being subjected to a number of stresses, and businesses and government agencies that support travel and tourism should collaborate in development and implementation of effective measures to reduce those stresses.

With respect to governance systems, discussions of climate and tourism focused on four key areas:

- facilities siting decisions;
- facilities design and construction;
- land management policies; and,
- emergency management/disaster preparedness.

Proactive, anticipatory approaches were universally encouraged, echoing calls for win-win or “no regrets” policies in the discussions of adaptation to climate change. One specific example often cited was reducing the risks associated with sea-level rise through proper planning for new facilities and infrastructure. Also encouraged were considerations of alternative approaches to infrastructure planning and governance, including the use of economic instruments (such as tax exemptions and subsidies) and innovative business-government partnerships as well as regulatory measures.

Discussions about governance also highlighted the importance of recognizing local cultural considerations and traditional approaches to land ownership, property rights and resource management. The phrase “one size does not fit all” was echoed throughout the Assessment, cautioning us to recall that what works in one island jurisdiction might not be appropriate in another. Similarly, the importance of incorporating traditional land ownership and stewardship practices reinforces the need to involve



*Like tourism, commercial agriculture in the Pacific, in this case pineapple cultivation in Hawai'i, is among the economic activities most directly affected by climate variability and change.*



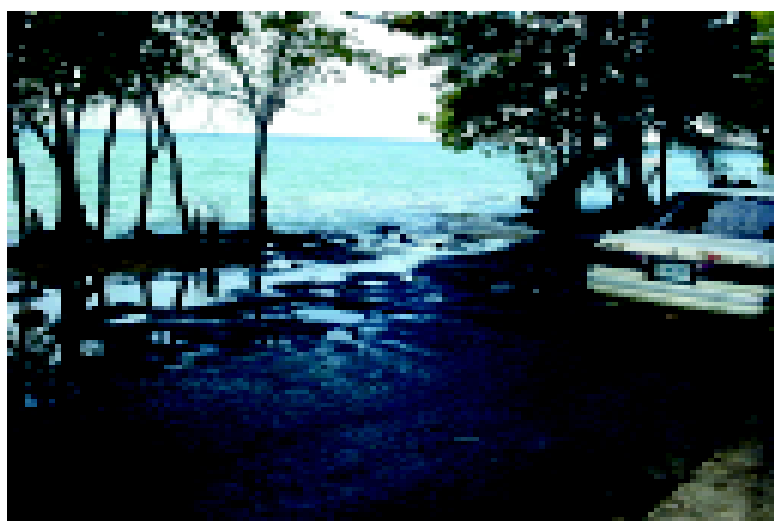
local communities and indigenous peoples in discussions of how governance might be changed to reduce the vulnerability of Pacific Islands to climate variability and change.

The importance of improving climate information and communication systems was noted throughout discussions of the climate/tourism nexus, and calls were made specifically for:

- improved forecast and warning systems for extreme events and other aspects of year-to-year climate variability;
- enhanced efforts to translate, interpret and disseminate information on climate variability and change in a form useful to the tourism industry and government agencies charged with infrastructure planning and support;
- baseline information on the consequences of current patterns of climate variability for the tourism industry;
- baseline information on critical resources and infrastructure from which to measure/monitor the effects of climate change over the long term;
- improved information on the specific regional and local impacts of climate change projections; and,
- education and public outreach programs to enhance public awareness and participation.

Underlying all of these recommendations was a call for more dialogue and interaction among the communities, businesses and government agencies affected by the consequences of climate variability and change for tourism in the Pacific Islands.

## Promoting Wise Use of



*Critical, low-lying infrastructure in the Pacific islands, like Weno Road in the Federated States of Micronesia, is particularly vulnerable to rising sea levels and related consequences of climate change (photo by Joseph Konno).*

## Marine and Coastal Resources

Coral reef ecosystems are considered highly vulnerable to long-term climate change. Yet, because they provide shoreline protection and habitat for important coastal and pelagic fish species, healthy reefs are important assets not only for tourism and fishing industries but also for residents of many islands. Unfortunately, significant coral bleaching events have been observed in association with recent ENSO events, and there are suggestions that such patterns might continue or increase with increased ocean temperatures. Climate variability and change pose other challenges for coral reefs, including increased water depth caused by sea-level rise, and the possibility of increased risk from tropical storms and hurricanes.

Changes in sea level present a number of challenges to island coastal communities, ecosystems and facilities. Sea-level variations associated with El Niño events can cause increased aerial exposure of coral reefs in some western Pacific jurisdictions, and flooding in low-lying areas toward the central and eastern equatorial Pacific. The consequences of accelerated sea-level rise have been the focus of most climate-change assessment efforts; they include increased risk of shoreline erosion, inundation of low-lying areas, damage from storm surge, and saltwater intrusion with its effects on important coastal ecosystems like mangrove forests, fresh-water resources and low-lying agricultural areas.

Also affected by climate variability and change are coastal and marine fisheries, which are integral to the culture and economies of many Pacific Islands. Numerous near-shore and reef-dwelling fish species are important components of the subsistence diet in small island communities, and climate-related changes in the habitats that support these fisheries would have consequences for those communities.

Recent scientific studies have revealed an important link between patterns of natural climate variability, such as the ENSO cycle, and the migratory patterns of important pelagic species like tuna. Hamnett, Anderson and Guard (2000) for example, suggest that the eastward expansion of warm water in the Pacific during an El Niño is associated with an eastward displacement of some commercially important tuna stocks such as skipjack. For many of the Pacific Islands in this Assessment, development of a viable tuna industry is considered an important component of their economic future. For example, in the FSM, the

## EFFECTS OF CLIMATE VARIABILITY AND CHANGE ON COASTAL AND MARINE RESOURCES:

- Changes in intertidal environments and species composition caused by sea-level rise
- Increased salinity in coastal estuaries caused by sea-level rise and periodic inundations from extreme events
- Changes in water quality in lagoons, with increased potential for red tides identified as a specific concern
- Changes in sea level, salinity and sediment loads (from erosion) that can affect mangrove forests (although the net effect of sea-level rise and climate change on mangroves is not well understood)
- Threats to seagrass beds from storm damage and increased sedimentation
- Changes in temperature, salinity and sea level that can have direct effects on coral reefs, which also are susceptible to siltation associated with storms and coastal erosion
- Changes in temperature and circulation in coastal and marine waters, which can alter spawning and foraging habitats for culturally and economically valuable species

tuna industry within its Exclusive Economic Zone (EEZ) is currently the primary focus for economic development in the country; access and license fees from distant-water fishing nations catching tuna in the EEZ are already a significant source of revenue (FSM, 1999). Starkist Samoa and Samoa Packing are the largest private sector employers in American Samoa, and are among the largest tuna canneries operating within U.S. territory (Hamnett and Anderson, 1999). Changes in the ENSO cycle or other climate-related changes in ocean circulation and productivity could bring significant changes to the location of tuna stocks, thus providing opportunities for jurisdictions that find themselves close to commercially-important stocks, and problems for jurisdictions that find themselves too far away.

### *Findings and Recommendations*

The effects of climate variability and change on Pacific Island marine and coastal resources can be categorized in two ways— effects on human populations and effects on the natural/biological resources upon which they depend. The most obvious effects on people are caused by extreme events. Heavy rains, winds and waves associated with hurricanes and tropical cyclones, for example, can threaten public safety and damage homes, businesses and infrastructure. Drought can reduce access to safe fresh-water resources, with implications for public health. Saltwater intrusion into fresh-water lenses, whether associated with

periodic events or long-term sea-level rise, can further jeopardize fresh-water resources, and saltwater inundation can threaten low-lying agricultural crops. Storm surge and sea-level rise can exacerbate coastal erosion—which is already significant in some areas— further endangering community infrastructure and homes. Human migrations to escape these risks can present significant challenges for both migrant populations and host communities; cultural differences and contrasting interpretations of traditional property rights and land ownership are among the potential difficulties.

Similarly, on islands where subsistence fishing is important, climate-induced changes in the productivity of marine and coastal ecosystems could alter carrying capacities. Food security issues could be particularly troublesome if declines in marine resources used for subsistence coincide with declines in agricultural productivity. And the economic viability of related industries such as mariculture could be affected by climate-related alterations in marine and coastal environments.

Marine fisheries represent an important element of Pacific Island economies. The pelagic or highly migratory tunas and billfishes of the Pacific are the basis for an extremely valuable fishery. About 70% of the world's tuna catch comes from the Western Pacific, and changes in ocean temperature associated with El Niño can significantly change the migratory patterns of commercially-important tuna stocks. The access fees that fishing companies pay Pacific Island jurisdictions to fish in their EEZs often represent a significant portion of the country's annual income. Even when a fisheries sector comprises only a small part of current GDP, as in the FSM, this sector is recognized along with tourism and commercial agriculture as providing long-term growth potential (FSM, 1999).

Pacific Island coastal waters support subsistence and commercial fisheries as well as valuable non-consumptive activities like recreational diving. Fish and other marine resources are important sources of protein for many Pacific Islanders. These resources can be affected by changes in water temperature and coral reef habitats, and by increased sedimentation associated with storms, floods and coastal erosion caused by climate variability and change. In addition, coastal ecosystems often have unique and important ecological and cultural value. (see boxed text for a summary of climate-induced effects on coastal resources.)

Recent scientific research also suggests that changes in ocean chemistry associated with increasing atmospheric concentrations of CO<sub>2</sub> may be at least as important for



*The dynamic nature of climate variability and change demands a flexible approach to coastal resource management that can address long-term trends such as sea-level rise, and accommodate year-to-year changes like those associated with El Niño.*

coral reefs as projected changes in ocean temperature and sea level. As increasing amounts of CO<sub>2</sub> infiltrate seawater, the carbonate saturation level of the water decreases. Preliminary findings suggest that increasing CO<sub>2</sub> levels could change seawater carbon chemistry sufficiently to affect the calcification rates, and hence growth, of coral and coralline algae; this in turn would affect the production of carbonate detritus, the source of sand necessary for beach building and shoreline maintenance.

In addition, insular marine ecosystems in the Pacific Islands have a great number of endemic species that have adapted to unique coastal conditions. Climate variability and change can alter the local environment and stress these endemic species, creating opportunities for invasion by alien species. Similarly, threatened or endangered species in critical island habitats could be further stressed by climate change. The endangered Hawaiian monk seal, for example, relies on unique nesting beaches and foraging habitats at the northern end of the Hawaiian archipelago. The added stresses of sea-level rise and storm-related impacts on these areas could be sufficient to move the seal (and other endangered species) closer to extinction. Marine ecosystems and species that are already heavily stressed due to over-harvesting or habitat alteration, for example, may be less resilient to climate variability and change. In this

context, protected marine areas might be a useful tool for reducing fishing stress and enhancing resilience.

Many ways were identified to enhance the resilience of Pacific Island communities and resources to the effects of climate variability and change. The first set of options focuses on development of flexible resource management approaches that accommodate climate variations. Central to these options is a commitment to routinely integrate information on climate variability and change into planning and regulatory regimes, as well as into resource harvesting decisions. In addition to improving the flow of information among scientists, governments, managers and businesses, this commitment requires sustained climate and ecosystem monitoring programs, improved research on climate/ecosystem interactions, and development of new modeling and assessment tools (e.g., fisheries and ecosystem forecast systems).

Emphasis was given to the importance of planning for extreme events and climate variability rather than just changes in mean conditions, and to evaluating projections of future conditions in the context of past events and historical data. Coastal managers encouraged the use of climate information, and identified some specific applications, including: use of ENSO-based rainfall forecasts to establish conditions for construction permits in areas subject to flooding and mudslides; incorporation of ENSO forecast information in decisions about the timing of restoration projects; integration of climate considerations in design of habitat-monitoring programs; and integration of climate information in growth-management plans. Island-specific case studies were recommended to help augment existing information on the consequences of climate variability and change. Also encouraged were targeted pilot projects such as development of sea-level data sets and hazard assessment tools for coastal managers and community planners. Finally, it was suggested that scientists and decision-makers supplement global analyses and regional forecasts with data on local indicators of changing climate. The value of programs like PEAC was acknowledged in the November 2000 Workshop, leading to general support for expanding regional abilities to develop and disseminate climate information.

Flexible resource management approaches require the development of policies that recognize that ecosystems are dynamic. Since climate variability and change produce considerable ecosystem change, management strategies that handle variations in fishery yields while protecting spawning potential will be necessary. Flexible resource management policies should be able to accommodate relocation of fishermen between fisheries, and respond

rapidly to changes in resource abundance. In this context, a policy is encouraged that incorporates risk, or a precautionary approach that recognizes the possibility of surprises and sets harvests at conservative levels. In addition to responding to changing climate and ecosystem conditions, such a policy would also evolve in response to changing social and cultural conditions.

Integrated resource management approaches can also be used to control risk when responding to the challenges of climate variability and change. For example, Kaluwin and Smith (1997) discuss integrated coastal zone management (ICZM) as a component of an effective response to the effects of sea-level rise and climate change. According to the Noordwijk Guidelines promulgated by the World Bank, the purpose of ICZM is “to maximize the benefits provided by the coastal zone and to minimize the conflicts of harmful effects of activities upon one another.” This same document refers to ICZM as a “governmental process” consisting of “the legal and institutional framework necessary to ensure that development and management plans for coastal zones are integrated with environmental (including social) goals and are made with the participation of those affected.” (World Bank, 1993)

It was agreed in the November 2000 Workshop that ICZM could provide a valuable framework for climate adaptation in Pacific Islands. In addition, emphasis was placed on the idea that “all those affected” should participate in development of an ICZM process; these include resource managers, government agencies, traditional knowledge sources, policymakers, community leaders, businesses, and scientists from various disciplines. Collaborating to combine the insights and interests of these parties was seen as essential to development of any such integrated resource management approach. Participants in the Pacific Assessment also reiterated the suggestion by Kaluwin and Smith (1997) that the general concept of ICZM will require some modification to accommodate the “Pacific Way.” Specifically, Kaluwin and Smith recommended a Pacific ICZM approach that recognizes:

- a high level of community involvement in coastal resource use and management;
- a high level of subsistence economic activity based on coastal resources and, therefore, an intimate involvement with the resource;
- strong customary land and marine tenure systems;
- Existence of strong indigenous cultures with traditional (and widely accepted and appropriate) decision-making and management mechanisms for natural resource management;
- cultures and communities that are closely attuned to the concepts of family and community and the need

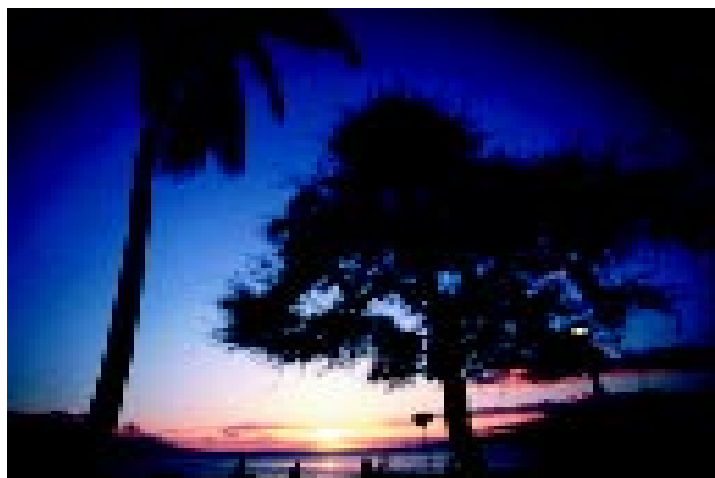
for sharing resources;

- a consensus approach to decision-making; and,
- customary resource management practices that are largely of an integrated nature, not sectoral.

In this latter context, Hawai‘i’s traditional ahupua‘a management system was identified as an example of such a customary management practice.

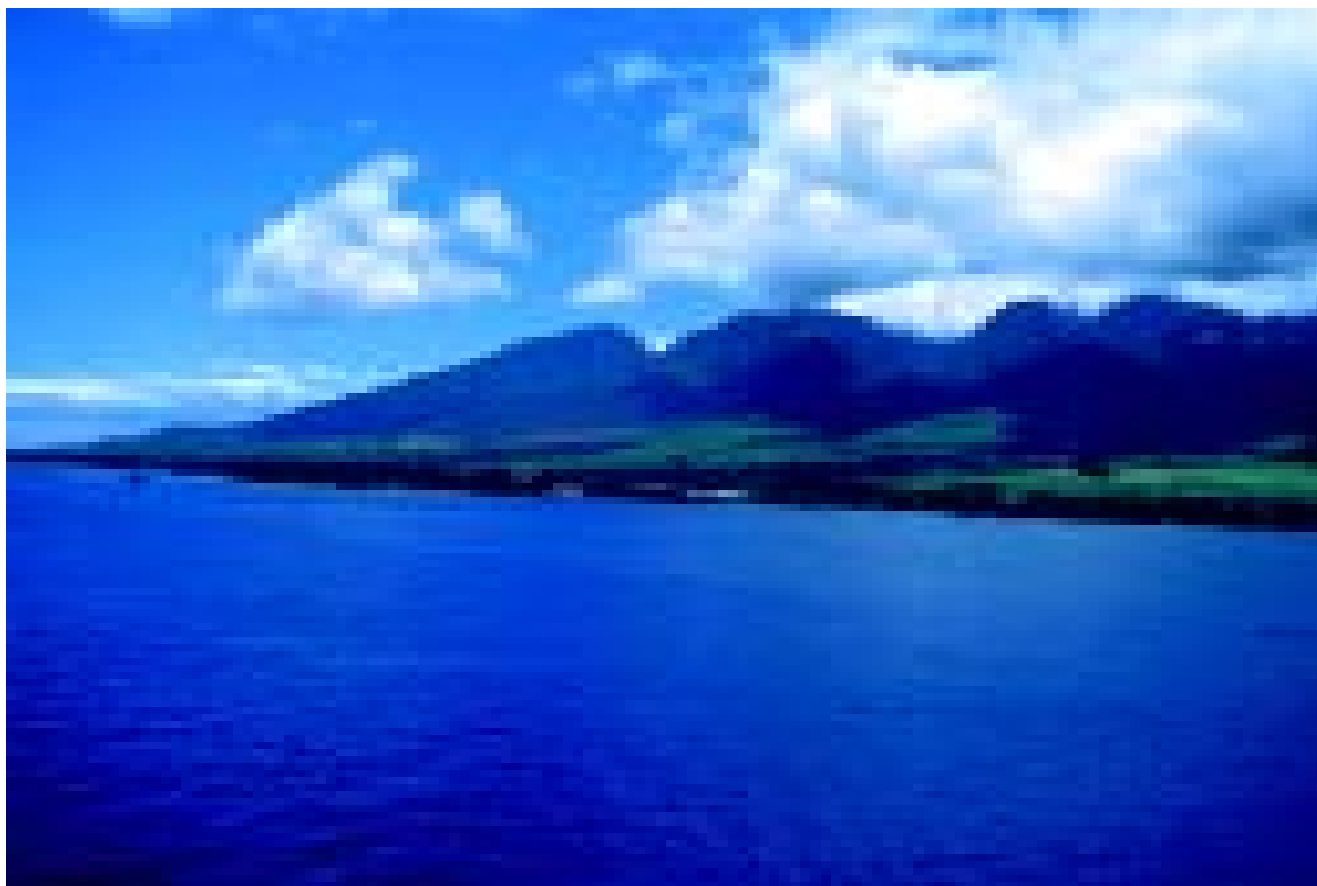
Reducing the risk of economic losses is another aspect of responding to the effects of climate on Pacific Island marine and coastal resources. It was suggested, for example, that in responding to the effects of the ENSO cycle on important tuna stocks, island states might consider regional agreements that rely upon revenue sharing to reduce variation in income from fishing access fees; this would assure that annual income for any one EEZ would be better insulated from fluctuations in fishing in that EEZ. Variation in resource abundance could result in overcapitalization during periods of great abundance, which should be avoided to minimize economic and management difficulties during a decline. To reduce this and related risks, island states were encouraged to reduce their dependence on single fishery sectors; corporations were encouraged to diversify their areas of operation, and fishermen were encouraged to diversify their target species and fishing techniques. Also suggested was development of aquaculture, mariculture and enhancement techniques for wild stocks, although it was recognized that these activities might also be affected by climate variability and change.

It was recommended that effective policies and procedures be developed to control the introduction of alien species, thereby reducing the vulnerability of marine and coastal resources. This could include, for example, procedures to



*Participants in the Assessment noted that the consequences of climate change for the Pacific Islands could be both negative and positive— but in any case should be anticipated and addressed through collaborative planning and mitigation.*





*The health of marine and terrestrial ecosystems in the Pacific Basin is dependent to a large degree on climate. Continued research and collaborative planning will enhance the ability of Pacific Islanders to anticipate and respond to the effects of climate variability and change—and maintain the health of their ecosystems.*

evaluate introduction of species for trade or mariculture, and consideration of the possibility that climate change can alter local environments, making it easier for exotics to become established.

It was agreed that successful integration of climate information into routine decision-making will require development of local cadres of knowledgeable individuals. Educational outreach was encouraged to increase the public's awareness and understanding of the consequences of climate variability and change and to increase the availability of useful and usable climate information. Outreach efforts should be designed to provide climate information that is simple, unambiguous and culturally appropriate; to expand the availability of climate curricula, particularly for K–12 classrooms; and to develop and disseminate climate information tailored specifically for target audiences such as local planning bodies, government agencies, industry groups and communities.

## Common Themes

In addition to the findings and recommendations aimed at reducing climate-related vulnerability in individual sectors, a number of common themes emerged from Pacific Assessment discussions of the consequences of climate

variability and change.

For all activities, current patterns of climate variability (most notably ENSO events) already present significant challenges for Pacific Island communities, and significant benefits can accrue from enhancing capabilities to anticipate and adapt to those events.

To respond effectively to climate variability and change, an information-intensive endeavor, there is a need for timely, useful and usable information derived from a continuing dialogue among scientists and decision-makers.

When thinking about climate-related vulnerability, it is important to consider the effects of climate on multiple, interacting sectors or activities, as well as within specific sectors or activities (e.g. the effects of climate change on fresh-water resources has implications for public health, agriculture, tourism and coastal resources). Effective responses can only be developed after consideration of all these interactions. In addition to considering interactions among sectors, there is a need to promote consistency in planning and policy formulation at different levels of government, from local to regional, and with sponsoring or donor agencies outside the region.

In all topical areas addressed by the Pacific Assessment,

participants highlighted the absence of reliable baseline information and the lack of island-specific vulnerability studies. Addressing this gap was identified as a high priority for continuing climate assessment activities in the Pacific.

There is a need for more formal and informal education, training and public outreach to strengthen efforts to anticipate and respond to the consequences of climate variability and change.

And finally, there is a need for proactive, forward-looking approaches to responding to climate variability and change— precautionary approaches that allow greater flexibility in response and reduce the adverse effects of surprises, as well as the costs of responding. This approach was characterized earlier in this Chapter by the Carolinian word “meninkairoir,” which means “taking the long view.”



# CHAPTER FOUR— PLANNING FOR THE 21st CENTURY

## Responding to Climate Variability and Change in the Pacific Islands

Participants in the Pacific Assessment were asked to consider not only the effects of climate in island settings but also what island communities could do to respond to those effects. In addition to the sector-specific findings and recommendations described in Chapter Three, a number of shared principles have emerged to guide climate response strategies in Pacific Island communities:

- Respect the unique circumstances of island communities, and the political, cultural, economic and environmental diversity among island communities;
- Strengthen partnerships among scientists, businesses, governments and communities through a continuous dialogue that identifies information needs and supports decision-making;
- Pursue flexible resource management and response options that accommodate surprises and facilitate adaptation to natural variability;
- Emphasize a proactive, precautionary approach to addressing the consequences of climate variability and change, and provide for continuous integration of new science and decision-making;
- Leverage the capabilities and resources of existing programs and organizations to respond to climate variability and change;
- Address stresses and constraints on critical infrastructure such as water distribution systems, and on community services like public health;
- Enhance access to climate information to better address today's problems while developing new insights and planning for the future; and,
- Recognize the need to secure and sustain the necessary human and fiscal resources, and pursue education, training and capacity-building as a fundamental commitment.

### The Uniqueness of Island Communities

Throughout the Assessment, participants emphasized the need to recognize the special characteristics of island communities when thinking about climate vulnerability

and response options. Concerns raised during the Assessment echoed earlier discussions of the vulnerability of island communities to natural hazards such as those summarized by Leatherman in *Island States at Risk: Global Climate Change, Development and Population* (1997). Among the issues of island vulnerability identified by Leatherman (and emphasized during the Assessment) were:

- The unique natural and cultural assets of each island jurisdiction;
- The small geographic size and limited resource base of island communities;
- The relative isolation of island communities, including issues related to their distance from markets and their reliance on shipment of goods and materials by air or sea;
- The susceptibility of many island communities to weather extremes such as hurricanes, and other natural hazards;
- The susceptibility of island economies to external shocks, and the often low resilience of the subsistence economies found on many islands; and,
- Constraints on fiscal and human resources, and limited access to data and information.

In discussing some island-specific limitations of the IPCC Common Methodology for coastal vulnerability assessments in the Pacific, Kaluwin and Smith (Leatherman, 1997) identified the need to consider additional issues such as:

- The close ties of people through customary land tenure;
- Gift-giving and readmittance as a mechanism for extended family economic resilience;
- Lack of urban land-use planning or building codes in some jurisdictions;
- Ineffective linkages among levels of government;
- The decision-making powers of village communities; and,
- The strength of religious beliefs.

In addition, participants in the Assessment stressed the importance of treating traditional knowledge and indigenous resource management practices as potential assets when considering options to reduce the vulnerability of Pacific Island communities to changes in climate.



## FOCUS: CRITICAL RESEARCH AND INFORMATION NEEDS

The following information and research needs could also be addressed to enhance the capability of Pacific Island communities to respond to climate variability and change.

### Providing access to fresh water

- \* Prepare island-specific inventories of freshwater resources available from rainfall, surface water, groundwater and submarine groundwater discharges (freshwater flows that emerge below the high tide level along the coast);
- Develop historic baseline information for water tables;
- Evaluate groundwater capacity;
- Prepare long-term forecasts of climate variability (ENSO and monsoon activity), paying particular attention to advance prediction of drought events, especially onset, severity, duration and demise;
- Sustain commitments to collection of basic data on rainfall, stream flow, water/well levels, and climate; and,
- Develop enhanced demographic mapping capabilities that can be combined with other data.

### Protecting Public Health

- Enhance studies and expand information on the links between climate variables (e.g. temperature, rainfall and tropical cyclones) and infectious diseases (including vector-borne diseases and freshwater and diarrheal diseases);
- Identify disease- and vector-specific environmental triggers and thresholds;
- Improve understanding of the health-related consequences

of climate variability and change on key sectors, particularly water resources and agriculture;

- Encourage integration of local knowledge and traditional adaptation practices in the development and implementation of response strategies;
- Explore “contextual vulnerability” in terms of nutritional status, immune status, previous control efforts and previous experience with extreme events, especially droughts;
- Conduct case studies to document use of climate forecast information in health applications, and address issues related to the multi-year sequences of events that link climate variables to changing health conditions;
- Compile the results of United Nations and other studies of healthcare, public health and disasters in the Pacific, and create linkages to existing public health and emergency response information centers and programs;
- Update plans for provision of healthcare services and emergency healthcare plans;
- Reconcile differences in scale among climate, health, socioeconomic and other data, and adapt Geographic Information Systems (GIS) for use in studies of climate in island settings;
- Develop higher-resolution data on both climate and health variables, and localized data on climate and health;
- Develop and evaluate new methodological approaches to supplement current statistical methods, which do not always work for climate and health studies.

*see “Critical Research Needs” on next page...*

## Research Requirements

A number of critical information gaps and high-priority research needs were identified that should be addressed to reduce vulnerability to climate changes. In particular, data on climate change at the local or regional level in the Pacific Islands are often missing or inaccessible; specific priorities for future research include:

- Enhancing efforts to monitor, document, understand and model climate processes and consequences at local, island, national and regional levels;
- Strengthening support for research and observing systems for meteorological/atmospheric, oceanographic and terrestrial variables in Pacific Islands, including the engagement of local observers and practitioners in the design and operation of climate observing systems;
- Improving information on the nature and consequences of climate conditions such as temperature, rainfall, tropical storms and trade winds, as well as patterns of natural variability (including ENSO and PDO) and how they might change;

- Developing reliable projections of climate change and predictions of climate variability on various timescales;
- Improving baseline information, including that on the physical, human and built environments, to better support monitoring and assessment studies at local, island, national and regional scales;
- Improving historical data sets that incorporate observations and insights from scientific and traditional sources (including anecdotal data) to better document past climate variability and the resilience of Pacific Island communities and ecosystems;
- Improving understanding of extreme events, from the frequency and severity of tropical cyclones and ENSO events to trends in heavy precipitation, including current patterns of frequency and severity and improved projections of how those patterns might change;
- Enhancing information on patterns of resource use, ecosystem change and species diversity at local, island, national and regional levels, including information from local practitioners on habitat changes and resource availability in areas traditionally used for

### **Ensuring Public Safety in Extreme Events and Protecting Community Infrastructure**

- Develop site-specific models of climate change consequences for extreme events;
- Improve understanding of the South Pacific Convergence Zone, the Intertropical Convergence Zone, and the Pacific Decadal Oscillation (also known as Interdecadal Pacific Oscillation) as they affect extreme events;
- Conduct topographic, hydrographic and other mapping at higher resolutions to better support risk analyses of islands, atoll islands in particular;
- Improve and diversify tools used to assess economic and social impacts of climate extremes;
- Conduct island-specific vulnerability assessments of at-risk populations, critical industries and infrastructure;
- Assess and identify critical gaps in emergency response capabilities, including the roles of agencies at all levels of government;
- Continuously monitor sea-level variability and trends over the short- and long-term, and use the data to examine inundation and flooding and develop predictive capabilities; and,
- Formulate contingency plans for specific disasters in each island jurisdiction.

### **Sustaining Agriculture**

- Collect and disseminate information on drought- and salt-resistant varieties of subsistence and cash crops that have proven resilient in Pacific Island settings;
- Improve access to climate variability forecasts (e.g., ENSO forecasts) for agricultural agencies, extension agents, farmers and ranchers;
- Conduct additional research on the implications of the loss of freshwater lenses due to climate variability and change, for both marine and terrestrial ecosystems;
- Enhance information on the relationship between droughts and mangrove die-back;
- Evaluate alternative crops that are less susceptible to drought damage and are acceptable alternatives to traditional crops; and,
- Evaluate wildfire risk-models used in Pacific Islands.

### **Sustaining Tourism**

- Document the effects of current climate conditions on the tourism industry;
- Improve forecasts of climate variability and develop more definitive projections of the consequences of climate change on the tourism industry;
- Develop appropriate baseline information on climate and communities, and monitor change over time;
- Enhance information about the effects of climate variability and change on the ecosystems and natural resources that sustain tourism, such as coral reefs, fisheries and forests;
- Improve understanding of the effects of climate variability and change on critical infrastructure (e.g., fresh water access, storage and distribution; accommodations; waste disposal; transportation; energy; communications; and food services);
- Improve understanding of the effects of climate variability and change on extreme events and other threats to public safety and health; and,
- Explore the direct and indirect consequences of proposed mitigation strategies on tourism (e.g., possible increases in fuel prices as a result of carbon taxes or other economic measures to reduce greenhouse gas emissions), and the potential impacts of tourism (e.g., land use/land cover change) on climate change and response options.

### **Promoting Wise Use of Marine and Coastal Resources**

- Improve information on the range of climate variability, and enhance understanding of ecosystem responses to climate variables such as temperature, salinity, precipitation and storms;
- Develop ecosystem and fisheries forecast models that integrate oceanographic and atmospheric data on patterns of climate variability and change;
- Identify indicators of sublethal, climate-related stress, as well as climate indicators with predictive, and hence management, value;
- Improve understanding of the interactions among land, water and coastal resources, and the consequences of climate variability and change for an integrated island system;
- Strengthen programs dedicated to long-term monitoring of ecosystems and relevant human activities, to ensure adequate documentation of baselines and responses to climate variability and change; and,
- Develop and use new tools to measure population abundance and productivity of fisheries.

subsistence gathering and fishing;

- Improving information on changing demographic, economic and environmental patterns and trends at the local, island, national and regional scales, including projected changes in development (e.g., population, infrastructure, etc.);
- Enhancing efforts to identify and evaluate adaptation measures;

- Enhancing efforts to document and understand the local, island, national and regional consequences of international climate change policies and mitigation measures;

- Developing standard methods and tools for data management and quality control; and,
- Enhancing communication and coordination among research institutions, data centers and regional

organizations/programs, and improving mechanisms for access to useful and usable information.

A great deal of additional research could be conducted and information gathered to enhance the capability of Pacific Island communities to respond to climate variability and change; these needs are itemized in the Focus sidebar “Critical Research and Information Needs.”

### *Digitizing Data from Oral Traditions and Historical Documents*

Participants in the Pacific Assessment highlighted the importance of incorporating data and information on local climate vulnerability and adaptation drawn from oral traditions and historical documents. One specific recommendation involves a focused effort to digitize these oral traditions and historical documents in written, photographic and video formats and compile them into a database indexed by place name, resource or practice. Combining these digitized records with GIS mapping tools could provide a means to juxtapose “then and now” visual perspectives or present climate data alongside information on historic and cultural practices.

This approach has recently been proposed as part of a program to monitor water quality in the Ala Wai Canal in Honolulu, where historic photographs of fishing in the canal could also be adapted for use in a climate monitoring system that would combine western science with traditional knowledge in a web-based information system (Stephen Kubota, personal communication).

## **Building and Sustaining Critical Partnerships**

Successful implementation of Assessment objectives will require long-term capacity building and development of new partnerships that can help reduce the vulnerability of island communities to climate change by:

- improving access to and use of information on climate variability and change to support decision-making;
- conducting additional research and analysis to improve our understanding of the sensitivity and exposure of island communities, and to enhance their resilience;
- supporting education and dialogue in communities, through which governments, businesses, resource managers and citizens can prepare for the challenges of



*Climate prediction and assessment depend upon information gathered at research facilities such as the NOAA atmospheric observatory atop Mauna Loa, in Hawai‘i; this facility provides sustained observations of CO<sub>2</sub> and other greenhouse gases that are vital to understanding the influence of human activities on the earth’s climate.*

climate variability and change; and,

- developing effective local, national and regional strategies to respond to climate variability and change.

Perhaps the most important aspect of these discussions was the conclusion that the Pacific Assessment should be a continuing process with an overarching goal of nurturing critical partnerships to develop climate information to support decision-making. These partnerships will enhance the ability of scientists and decision-makers throughout the Pacific to understand and respond to the challenges and opportunities presented by climate variability and change.

In this context, the Assessment can be viewed as part of a critical scientific and decision support system that will bridge the science-decisions “information gap” identified during the March 1998 Workshop and recognized as a problem throughout the Assessment. This bridge will help develop and convey new scientific insights that link global-scale processes to local impacts; it will also allow experts, decision-makers and information brokers to integrate their individual skills and informational assets to address climate-related problems along a continuum of time and space scales.

As depicted in Figure 1 (Chapter One), this “information bridge” originally focused on linking the scientific community with decision-makers (or “information users”) in government, businesses and communities. In their

## FOCUS: DEVELOPING A PACIFIC ISLANDS CLIMATE INFORMATION SYSTEM

In July 1999, the East-West Center and SPREP convened an informal meeting to discuss the concept of a Pacific Islands Climate Information System (PICIS)—a new mechanism to coordinate and focus the work of numerous organizations and programs engaged in climate observation, research, forecasting and assessment in the Pacific. In attendance at the meeting were representatives of SPREP, PEAC, and:

- several national meteorological services in the region, including the U.S. National Weather Service, the Australia Bureau of Meteorology, and the Fiji Meteorological Service;
- the South Pacific Applied Geosciences Commission (SOPAC);
- the World Meteorological Organization;
- the Schools of the South Pacific Rainfall Climate Experiment (SPaRCE);
- the University of Waikato's International Global Change Institute;
- the International Research Institute for climate prediction (IRI);
- the U.S. National Oceanic and Atmospheric Administration; and,
- the U.S. Department of Energy.

By the end of the meeting, participants had agreed to take the next steps in creation of a PICIS that would build a “knowledge bridge” between sources of scientific information and potential users of that information in Pacific Island communities, businesses and government agencies. Discussions at the meeting identified the following goal for a PICIS: Combine the unique assets and special expertise of national, regional and international institutions and programs to develop and strengthen a regional climate information system that will support decision-making in the context of climate variability and change. As discussed during the Tahiti meeting, the partners in the PICIS would pursue a number of specific objectives to fulfill this goal, including:

- sustain or enhance monitoring of critical climate-related

conditions and their environmental and socioeconomic consequences;

- provide access to emerging climate forecasting capabilities;
- support development and evaluation of new climate monitoring and prediction tools, and explore potential applications for those tools;
- transform global-scale predictions into regional forecasts tailored to incorporate local and regional processes and reflect the information needs of regional stakeholders;
- establish and sustain a dialogue among scientists, forecasters and other stakeholders to identify information needs and evaluate the quality, usefulness and usability of new climate forecasts and information products;
- enhance the expertise and technical capabilities of national meteorological services in the Pacific Region, and provide access to new tools and information to support their responsibilities;
- conduct research to improve understanding of the regional consequences of climate variability and change, and explore the potential application of enhanced climate information to support practical decision-making;
- provide information and analyses to help Pacific jurisdictions address the challenges of climate variability and change and sea-level rise, including national and international assessment programs and national efforts in response to the United Nations Framework Convention on Climate Change;
- support regional capacity-building through training, education and public outreach that improves technical capabilities and expertise throughout the region, and enhances public awareness of the consequences of climate variability and change; and,
- preserve free access to climate data and products for national meteorological services and other organizations in the Pacific Region. A PICIS Working Group has been organized under the auspices of the SPREP to pursue these objectives.

1999 report, *Our Common Journey: A Transition toward Sustainability*, the Board on Sustainable Development at the National Research Council (NRC) highlighted the importance of such regional information systems, which “harness scientific knowledge to support policy and decision-making affecting the interactions of environment and development” (NRC, 1999).

The NRC report further reinforces the importance of this “social process that builds links to different communities” as essential to assembly of the diverse information required

to understand and address regional environmental management. During the Assessment, this concept evolved into a call for a long-term process of shared learning and joint problem-solving that involves all parties interested in the consequences of climate change. Participants in the Assessment found a traditional analog for this multi-stakeholder dialogue in the Hawaiian institution of an ‘aha council. The ‘aha council was the principal mechanism for decision-making as it related to management of resources in the ahupua‘a, the ancient Hawaiian geopolitical land division.<sup>10</sup> The ‘aha council

<sup>10</sup> Ahupua‘a extended “from sea soil to the mountainside or top,” with broad bases anchored in offshore fishing grounds, and apexes in montane forests, providing almost all resources the chiefs and people needed to thrive on the most remote archipelago on the planet.



provided a forum for all experts in the ahupua'a to contribute to decisions about the natural resources on which they depended. Participants in the November 2000 Workshop suggested that this concept could be adapted to create an "aha council for climate" in the Pacific Islands.

Regardless of whether one thinks of climate assessment as a multidisciplinary, integrated scientific endeavor, or as a traditional approach to participatory resource management, the successful engagement of experts from all knowledge groups requires a shared commitment to a sustained effort to identify and respond to real problems facing people in the Pacific Islands. Participants in this Assessment are committed to this process and will pursue funding to ensure that partnerships established early in the assessment can be maintained and enhanced.

Other recommendations also emerged from discussions of cooperative partnerships during the Assessment; they include:

- Strengthen and sustain institutions and programs like the PEAC that support decision-making by providing and applying climate information;
- Integrate traditional cultural knowledge and practices by engaging traditional leaders, teachers and practitioners;
- Enlist the aid of religious and spiritual leaders to strengthen efforts to understand and respond to climate variability and change;
- Leverage the capabilities of information brokers skilled in the interpretation and translation of scientific, technical and cultural information, especially organizations like national meteorological services, universities, research institutions, scientific/environmental/economic organizations, and industry and professional associations;
- Encourage continued regional collaboration to strengthen individual and collective efforts;
- Pursue multidisciplinary scientific investigations to improve understanding of climate processes and consequences, and to foster partnerships with international climate science programs (e.g. World Climate Research Program efforts, including CLIVAR and the Global Climate Observing System, and research projects conducted under the auspices of the International Geosphere-Biosphere Programme and the International Human Dimensions of Global Change Program);
- Pursue partnerships with private companies, particularly in areas such as agriculture, tourism, water-resource management and infrastructure development;
- Establish cross-sectoral teams (e.g., water managers,

emergency preparedness experts and public health officials) to address common problems arising from climate variability and change;

- Support interisland cooperation in climate and health in order to leverage investments in areas such as disease control infrastructure, drugs and insecticides;
- Encourage integration of climate-related policies, plans and decisions across levels of government and between donor agencies; and,
- Enlist decision-makers in the identification of climate information needs, then establish "science user teams" to develop and regularly improve climate information products to meet those needs.

Also highlighted was the importance of building trust among the diverse involved groups representing scientists, businesses, government agencies and community leaders. Achieving this objective also requires sustained cooperation and dialogue among scientists and decision-makers. As described in the Focus sidebar on the 1997–1998 El Niño (Chapter 2), the success of regional efforts to anticipate and respond to the 1997–1998 ENSO warm event was based in part on a history of outreach and education by the Pacific ENSO Applications Center; the success was also rooted in a sense of shared responsibility that had emerged among PEAC scientists and government officials throughout the region. Both groups emphasize that their sustained interaction prior to the ENSO warm event generated confidence in the quality of scientific information provided by PEAC, and in the ability of decision-makers to integrate that information into their decisions. The PEAC experience and discussions during the Assessment simply reiterate the value of this kind of sustained, interactive climate information system.

## Next Steps— A Look to the Future

In response to findings and recommendations developed during the Assessment, commitments were made to a number of specific actions. First and foremost, the core scientific team will work with colleagues and funding agencies to secure the resources required to sustain the dialogue and scientific exploration that characterizes the Assessment. Future efforts will be embedded within emerging plans for a Pacific Islands Climate Information System, as described earlier in this Chapter.

Other actions already under way or planned include:

- Development of collaborative research projects in areas



*The emerging Pacific Islands Climate Information System will combine the expertise of national, regional and international institutions to support social and political decision-making in the context of climate variability and change.*

such as the interaction of climate variability with infectious diseases, and the potential for use of the ahupua'a system, integrated with climate information, for watershed management in Hawai'i;

- Preparation of National Implementation Strategies in jurisdictions like the Federated States of Micronesia and the Republic of the Marshall Islands as part of the next phase of the SPREP-sponsored Pacific Islands Climate Change Assistance Programme;
- Identification of reports, graphics, and other informational materials that can be used to support education programs on climate variability and change in the region;
- Enhancement of education and training programs focused on the implications of climate variability and change for the Pacific Region (e.g., the vulnerability and adaptation course at the University of the South Pacific, and the February 2001 "Training Institute on Climate and Society in the Asia-Pacific Region" held at the East-West Center);
- Initiation of a series of small-group discussions with

indigenous community leaders to explore the meaningful integration of traditional knowledge into studies of the nature and consequences of climate variability and change;

- Initiation of a series of small-group meetings and workshops with businesses, government agencies and community representatives in key economic sectors such as tourism, fisheries and agriculture; and,
- Use of presentations and formal and informal publications to disseminate the results of the Assessment to a broader regional and international audience, including regional organizations and professional associations in key sectors.

## Concluding Thoughts

Rather than an end product, this report on the Pacific Assessment represents the beginning of a sustained process of dialogue and information exchange among scientists, businesses, governments and communities in the region. Working together, these diverse stakeholders can coordinate and leverage their assets and expertise to support a climate information partnership that will:

- clarify the information needs of decision-makers and identify critical information gaps to help guide future research;
- improve access to climate information and explore the use of innovative communication and decision-support tools;
- provide access to critical data and translate research results into useful information; and,
- increase the number of professionals who develop and use climate information to support decision-making, and expand education and training opportunities for them.

Together we can combine our individual assets and collective insights into a new paradigm of climate awareness and response. We can embrace the opportunity to use new scientific insights to improve the use of climate information to support decision-making. And we can — and will — surmount the challenges of climate variability and change and establish a closer partnership between the people of the Pacific and the climate system that sustains us.



*The Pacific Assessment has begun a dialogue amongst regional stakeholders that is intended to develop a new paradigm of climate awareness and response— and to surmount the challenges posed by changing climate.*

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## APPENDIX A— OVERVIEW OF THE NATIONAL ASSESSMENT

### *Rationale and Institutional History*

The influence of climate permeates life and lifestyles in the United States. Year-to-year variations are reflected in such things as the number and intensity of storms, the amount of water flowing in our rivers, the extent and duration of snow cover, and the intensity of waves that strike our coastal regions. Science now suggests that human activities are causing our climate to change. Although details are still hazy about the extent of changes to come in each region of the country, changes are starting to become evident. Temperatures have increased in many areas, snow cover is not lasting as long in the spring, and total precipitation is increasing, with more rainfall occurring in intense down-pours. These changes appear to be affecting plants and wildlife. There is evidence of a longer growing season in northern areas and changing ranges for butterflies and other species. The international assessments of the Intergovernmental Panel on Climate Change (<http://www.ipcc.ch>) project that these changes will increase over the next 100 years.

The Global Change Research Act of 1990 (Public Law 101-606) gave voice to early scientific findings that human activities were starting to change the global climate, reporting that “(1) Industrial, agricultural, and other human activities, coupled with an expanding world population, are contributing to processes of global change that may significantly alter the Earth’s habitat within a few generations; (2) Such human-induced changes, in conjunction with natural fluctuations, may lead to significant global warming and thus alter world climate patterns and increase global sea levels. Over the next century, these consequences could adversely affect world agricultural and marine production, coastal habitability, biological diversity, human health, and global economic and social well-being.”

To address these issues, Congress established the U.S. Global Change Research Program (USGCRP) and instructed federal research agencies to cooperate in developing and coordinating “a comprehensive and integrated U.S. research program that will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change.” Furthermore, Congress mandated that the USGCRP “shall prepare and submit to the President and the Congress an assessment which:

- integrates, evaluates, and interprets the findings of the Program and discusses the scientific uncertainties associated with such findings;
- analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity; and,
- analyzes current trends in global change, both human-induced and natural, and projects major trends for the subsequent 25 to 100 years.”

### *Objectives of the Assessment*

The USGCRP’s National Assessment of the Potential Consequences of Climate Variability and Change is being conducted under the provisions of this Act, and seeks to answer questions about why we should care about, and how we might effectively prepare for, climate variability and change.

The overall goal of the National Assessment is to analyze and evaluate what is known about the potential consequences of climate variability and change for the nation, in the context of other pressures on the public, the environment, and the nation’s resources. The National Assessment process has been broadly inclusive, soliciting and accepting public and private input from academia, government, and interested citizens. Starting with broad public concerns about the environment, the Assessment is exploring the degree to which existing and future variation and change in climate might affect issues that people care about. The Assessment has focused on regional concerns around the U.S. and national concerns for particular sectors, relying upon a short list of questions to guide the process; these questions are:

- What are the current environmental stresses and issues that form the backdrop for potential additional impacts of climate change?
- How might climate variability and change exacerbate or ameliorate existing problems? What new problems and issues might arise?
- What are the priority needs for research and information that can better prepare the public and policymakers to reach informed decisions about climate variability and change? What research is most important to complete over the short term, and over the long term?

- What coping options exist that can build resilience to current environmental stresses, and possibly also lessen the impacts of climate change?

### *Structure of the Assessment*

The National Assessment has three major components:

- Regional analyses— these consist of workshops and assessments conducted to identify and define the potential consequences of climate variability and change in regions spanning the U.S. Twenty workshops were held around the country, with the Native Peoples/ Native Homelands Workshop being national in scope rather than regional. To date, sixteen workshop groups have prepared assessment reports that address the particular interests of people in their regions by focusing on regional patterns and textures of changes where people live. Most workshop reports are already available at <http://www.nacc.usgcrp.gov>, with the final reports becoming available in late 1999.
- Sectoral analyses— these consist of workshops and assessments carried out to characterize the potential consequences of climate variability and change for broad sectors that encompass environmental, economic, and societal concerns. The sectoral reports analyze how the consequences in each region affect the nation, making the reports widely interesting and national in scope. The sectors studied in the first phase of the ongoing National Assessment include agriculture, forests, human health, water, and coastal areas and marine resources. Publications and assessment reports became available starting in late 1999.
- The National Overview— which consists of a summary and integration of findings from the regional and sectoral studies, and conclusions about the importance of climate variability and change for the United States. The National Assessment Synthesis Team was responsible for this report, which became available in the spring of 2000.

Each of the regional, sectoral, and synthesis activities was led by a team of experts from the public and private sectors, including university and government personnel and a wide spectrum of stakeholders from our communities. Their reports went through an extensive review process involving experts and other interested stakeholders. The assessment process is supported cooperatively by USGCRP agencies including the Departments of Agriculture, Energy, Health and Human Services, Interior, and Commerce (National Oceanic and Atmospheric Administration), as well as the Environmental Protection Agency, the National Aeronautics and Space Administration, and the National Science Foundation. Through this collaboration, the

USGCRP hopes to cultivate broad understanding of climate-related issues and their importance for the nation, and a full range of perspectives about how best to respond.

Extensive information about the Assessment, about members of assessment teams, and about links to activities in various regions and sectors, is available over the Web at <http://www.nacc.usgcrp.gov>, or by inquiry to the Global Change Research Information Office / P.O. Box 1000 / 61 Route 9W / Palisades, New York 10964.

*Prepared by Michael MacCracken*

*National Assessment Coordination Office*

*Revised October 5, 1999*

## APPENDIX B— MEMBERS OF THE PACIFIC ASSESSMENT CORE SCIENTIFIC TEAM

### Principal Investigator:

Eileen L. Shea  
Climate Project Coordinator  
East-West Center

### Project Co-Investigators:

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Director, Social Science Research Institute  
University of Hawai‘i

Glenn Dolcemascolo  
Research Associate  
East-West Center

Cheryl L. Anderson  
Planner and Policy Analyst  
Social Science Research Institute  
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### Key Scientific Contributors:

Anthony Barnston  
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International Research Institute for Climate Prediction  
Columbia University

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Climate and Global Dynamics Division  
National Center for Environmental Research

Nancy Lewis  
Acting Dean, College of Social Sciences  
University of Hawai‘i

Charles (Chip) Guard  
Water and Environmental Research Institute  
University of Guam

Johannes Loschnigg  
Post-doctoral Fellow  
International Pacific Research Center  
University of Hawai‘i

## APPENDIX C— MEMBERS OF THE PACIFIC ASSESSMENT STEERING COMMITTEE

Mr. Clement Capelle  
Chief, National Disaster Management Office  
Republic of the Marshall Islands

Professor Thomas Giambelluca  
Department of Geography  
University of Hawai‘i

Dr. Sitiveni Halapua  
Director, Pacific Islands Development Program  
East-West Center

Dr. John Hay  
International Global Change Institute  
University of Waikato, New Zealand.

Mr. Clyde Mark<sup>1</sup>  
Outrigger Hotels and Resorts  
Honolulu, Hawai‘i

Dr. Gerald Meehl  
Climate & Global Dynamics Division  
National Center for Atmospheric Research

Mr. Gerald Miles, Head  
Environmental Management and Planning Division  
South Pacific Regional Environment Programme

Mr. John Mooteb  
Climate Coordinator  
Government of the Federated States of Micronesia

Dr. Wali Osman  
Vice President & Regional Economist  
Bank of Hawai‘i  
Honolulu, Hawai‘i

Mr. Lelei Peau  
Economic Development & Planning Office  
Government of American Samoa

Mr. Techur Rengulbai, Chief  
Bureau of Public Utilities  
Ministry of Resources and Development  
Republic of Palau

Dr. Robert Richmond  
Professor of Marine Biology  
University of Guam Marine Laboratory

Ms. Kitty Simonds, Executive Director  
Western Pacific Regional Fishery Management Council  
Honolulu, Hawai‘i

Dr. Thomas Schroeder, Director  
Joint Institute for Marine and Atmospheric Research  
University of Hawai‘i

### Federal Liaisons to the Steering Committee

Richard Hagemeyer  
National Weather Service-Pacific Region  
National Oceanic and Atmospheric Administration

Mr. Charles Karnella<sup>2</sup>  
Pacific Islands Area Office  
National Marine Fisheries Service  
National Oceanic and Atmospheric Administration

Mr. David Kennard  
Region IX, Pacific Area Office  
Federal Emergency Management Agency

Dr. David Kirtland  
U.S. Geological Survey  
U.S. Department of the Interior

Mr. Joe Lees  
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U.S. Fish and Wildlife Service  
U.S. Department of the Interior

Dr. Roger Pulwarty  
Office of Global Programs  
National Oceanic and Atmospheric Administration

Dr. Thomas Spence  
Geosciences Directorate  
National Science Foundation

<sup>1</sup> Mr. Mark resigned from the Steering Committee upon leaving Outrigger in the summer of 2000.

<sup>2</sup> In Mr. Karnella's absence, the Pacific Islands Area Office was represented by Mr. Kelvin Char.

## APPENDIX D— WORKSHOP ON CLIMATE AND ISLAND COASTAL COMMUNITIES— NOVEMBER 2000

### Workshop Summary

*November 6-8, 2000*

*East-West Center, Honolulu, Hawai'i*

In November 2000, the East-West Center hosted an exciting, three-day Workshop on Climate and Island Coastal Communities that provided a unique forum for business leaders, scientists, government representatives, public interest groups and community leaders to jointly explore opportunities to address the significant challenges that climate variability and change present to Hawai'i and other island jurisdictions throughout the Pacific and the Caribbean. The Workshop was organized as part of a Pacific Islands Regional Assessment project funded by the National Science Foundation (NSF), on behalf of NSF, the National Oceanic and Atmospheric Administration, the National Aeronautics and Space Administration and the U.S. Department of the Interior. The results of this project will provide a Pacific regional contribution to the first U.S. National Assessment of the Consequences of Climate Variability and Change; the National Assessment was organized under the auspices of the U.S. Global Change Research Program and the White House Office of Science and Technology Policy.

The November 2000 Workshop was designed to achieve two mutually-supportive objectives:

- To develop a more complete understanding of the regional consequences of climate variability and change for Pacific Island jurisdictions in the context of other economic, social and environmental stresses; and
- To initiate and sustain a dialogue among scientists, governments, businesses and communities in the Pacific region that promotes use of climate information to support practical decision-making.

As EWC President Charles Morrison noted in his letter of welcome to Workshop participants, "climate variability and change, like so many critical issues facing the Asia-Pacific Region, require creative approaches that bring governments, businesses, communities and scientists together in innovative, new partnerships." The theme of sustaining critical partnerships was reflected throughout the Workshop and provided the focus for an inspirational closing keynote address by Puanani Burgess.

Rather than the traditional approach of identifying and quantifying impacts, the Workshop was organized around

the concept of climate vulnerability. This conceptual framework enabled participants to explore not only issues of climate sensitivity and exposure but also the ability of communities, ecosystems, and businesses to respond (adapt) to climate impacts. Reflecting this focus on identifying and promoting appropriate action, most of the Workshop deliberations took place in highly-interactive working-group discussions of the implications of climate variability and change for key aspects of island life; these include:

- providing access to fresh water;
- protecting public health;
- ensuring public safety and protecting community infrastructure;
- sustaining tourism and agriculture as key economic sectors; and,
- promoting wise use of coastal and marine resources.

In each of these areas, Workshop participants provided valuable insights into how Pacific Island jurisdictions can reduce climate sensitivity and exposure and enhance their adaptive capacity — build resilience - to the significant challenges presented by climate variability and change. Detailed findings and recommendations in each of these critical areas are being incorporated into the Pacific Islands Regional Assessment report scheduled to be completed in spring 2001.

EWC Climate Project Coordinator Eileen Shea has summarized a number of important general findings that emerged from the Workshop. First is the strong endorsement of a commitment to continuing a Pacific Islands climate dialogue that engages experts from all knowledge groups— each bringing its own unique insights and experience to the table in a joint effort to understand and respond to a shared challenge. Establishing and sustaining these critical partnerships in research, dialogue and education emerged throughout the Workshop as the fundamental key to effectively responding to the challenges of climate variability and change. Embedded within this commitment should be the meaningful integration of traditional knowledge and practices into the paradigm of western science and technology. Kumu Hula John Ka'imikaua set the stage for this important concept in his keynote presentation of story, chant and dance, which provided exciting examples of the insights that can be drawn from traditional knowledge of weather and climate



in the Native Hawaiian community. Other key findings included recommendations related to:

- Enhancing efforts to interpret and communicate climate information;
- Pursuing proactive (rather than reactive) policy options with a sustained commitment to adaptation and integration of climate information into planning, decision-making and policies at all levels of government;
- Using climate information to address today's problems today— e.g., responding to the dramatic year-to-year climate fluctuations like the 1997–1998 El Niño;
- Recognizing the special characteristics of island communities, including their unique natural and cultural assets, the limitations imposed by their geographic size and isolation, and their dependence on critical natural resources (e.g., coral reefs) and climate-sensitive economic sectors (e.g., agriculture and tourism);
- Addressing the consequences of extreme events (e.g., changes in patterns of droughts and tropical storms) as well as long-term trends (e.g., rising sea level); and,
- Filling critical information gaps, including the development of regional and local-scale information on climate processes and consequences.

The November 2000 Workshop on Climate and Island Coastal Communities reflected an emerging paradigm of climate (and other environmental) assessments as a sustained process that combines scientific exploration with an effective science<>policy dialogue. This paradigm suggests that, in a practical sense, a commitment to a climate assessment mission means a commitment to supporting the emergence of a climate information system designed to meet the needs of decision-makers. As EWC President Charles Morrison noted in his letter of welcome, “The Workshop’s approach of combining research, dialogue and education mirrors the mission of the East-West Center itself, supporting the emergence of such new partnerships in progress toward an Asia-Pacific community committed to shared learning and joint problem-solving.”

**Contact:** Eileen L. Shea  
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## Workshop Agenda

*Workshop on Climate and Island Coastal Communities  
November 6-8, 2000*

### MONDAY, NOVEMBER 6 (PLENARY)

- |            |  |
|------------|--|
| 8:00 a.m.  | Workshop Registration<br>Continental Breakfast   |
| 9:00 a.m.  | Opening Plenary<br>Oli Aloha<br>Welcome<br>Opening Remarks<br><br>Opening Keynote:<br>Huli Ka Lani Kanu Pono Ka Honua<br>“When the Heavens Change, the Earth<br>is Planted Accordingly”<br><i>Kumu John Ka'imikaua and<br/>Halau Kukunaokala</i> |
| 10:30 a.m. | Break  |
| 11:00 a.m. | Overview of Workshop Objectives and<br>Organization<br><i>Eileen L. Shea – East West Center</i>  |
| 11:15 a.m. | The Concept of Vulnerability<br><i>Ricardo Alvarez – International<br/>Hurricane Center</i>  |
| 12:15 p.m. | Lunch (Imin Center Garden Level)<br>Video Presentation:<br>A Mau A Mau: To Continue Forever  |
| 1:30 p.m.  | <i>The Honorable Neil Abercrombie:<br/>U.S. House of Representatives</i>   |
| 1:45 p.m.  | Discussion of Working Group Structure<br>and Goals<br><i>Mike Hamnett— Social Science Research<br/>Institute<br/>Eileen Shea<br/>Ricardo Alvarez</i>   |
- Anticipated Goals and Products -Why are we here?
  - Introduction of Working Group Topics/Key Issues
    - Access to Fresh Water
    - Protecting Public Health

- Ensuring Public Safety in Extreme Events and Protecting the Built Environment/Community Infrastructure
- Sustaining Tourism and Agriculture
- Promoting Wise Use of Coastal and Marine Resource

## Overview of Key Working Group Questions

- What systems, activities, communities (and populations) are particularly sensitive to climate and how?
- How might we respond to enhance the adaptive capacity of these systems, activities communities (and populations)?
- What information/research is needed to reduce sensitivity or enhance adaptive capacity (build resilience)?
- How can information about climate be used to enhance planning, policy formulation and decision-making?
- What cooperative partnerships could be pursued to enhance adaptive capacity?

2:45 p.m. Break

3:15 p.m. Overview of Climate Change Scenarios  
for Workshop Deliberations  
*Tony Barnston:*  
*International Research Institute for*  
*Climate Prediction*

4:00–5:30 p.m. Convene in Working Groups  
(Introductions, summary of key issues,  
work plan)

6:15–8:30 p.m. Opening Reception (Waikiki Aquarium)

## TUESDAY, NOVEMBER 7 (WORKING GROUPS)

8:00 a.m. Continental Breakfast

9:00 a.m. Working Groups Reconvene

12:00 (noon) Convene in Plenary for Quick Updates  
and Identification of Issues/Problems  
(Boxed Lunches Provided)

## Workshop Steering Committee

*Workshop on Climate and Island Coastal Communities*

Cheryl L. Anderson  
Social Science Research Institute  
University of Hawai‘i

Ricardo Alvarez  
International Hurricane Center  
Florida International University

Kelvin Char  
Pacific Islands Area Office  
National Marine Fisheries Service (NOAA)

Lynette Hi‘ilani Cruz  
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East-West Center

# Working Group Chairs and Rapporteurs<sup>3</sup>

## *Workshop on Climate and Island Coastal Communities*

### *Providing Access to Freshwater*

#### **Working Group Co-Chairs**

Techur Rengulbai  
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Republic of Palau

Tom Giambelluca  
Geography Department  
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Robert Hadley  
Government Water Engineer  
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#### **Rapporteur**

Cheryl Anderson  
Social Science Research Institute  
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### *Protecting Public Health*

#### **Working Group Chair**

Nancy Lewis, Acting Dean  
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#### **Rapporteur**

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### *Ensuring Public Safety and Protecting Community Infrastructure*

#### **Working Group Co-Chairs**

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Pene Lefale  
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### *Sustaining Tourism*

#### **Working Group Co-Chairs**

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Alan Parker, Director  
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#### **Rapporteur**

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### *Sustaining Agriculture*

#### **Working Group Co-Chairs**

Michael Hamnett  
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Eric Enos  
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#### **Rapporteur**

Michael Hamnett  
Social Science Research Institute  
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### *Promoting Wise Use of Coastal and Marine Resources*

#### **Working Group Co-Chairs**

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Andy Tafleichig  
Yap Marine Resources Management  
Federated States of Micronesia

#### **Rapporteur**

Lynne Carter  
National Assessment Coordination Office

<sup>3</sup> These individuals were responsible for leading discussions of vulnerability in each of the six key activity areas addressed during the November Workshop; the reports of their deliberations provided a foundation for the final Pacific Islands Regional Assessment Report.

# Participants

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# APPENDIX E— WORKSHOP ON THE CONSEQUENCES OF CLIMATE VARIABILITY AND CHANGE FOR HAWAI‘I AND THE PACIFIC: CHALLENGES AND OPPORTUNITIES— MARCH 1998

## Workshop Summary

*March 3–6, 1998*

*East-West Center in Honolulu, Hawai‘i*

This document provides a brief summary of the Workshop on the Consequences of Climate Variability and Change for the Hawai‘i-Pacific Region: Challenges and Opportunities. The Workshop was organized under the auspices of the White House Office of Science and Technology Policy and the U.S. Global Change Research Program as part of the initial phase of the first U.S. National Assessment of the Consequences of Climate Variability and Change. Additional details on the history, rationale, objectives and organization of the Workshop can be found in the Workshop Background Paper generated as a supplement to this summary. Following is a brief summary of the Workshop deliberations.

### *Objectives and Organization*

The March 1998 Workshop was designed to provide representatives of business, government, public interest groups and the scientific community with an opportunity to:

- Initiate a long-term, interactive dialogue on the sensitivity of communities, businesses and ecosystems to climate change; and
- Explore opportunities for use of new scientific information to adapt to or mitigate the consequences of those changes.

During the opening plenary session on March 3, Workshop participants were provided with a number of individual and panel presentations designed to address what climate variability and change means for the Pacific Region from three points of view:

- A climate system perspective;
- A community planning and economic development perspective; and,
- A habitat and natural resource perspective.

On the second day of the Workshop, participants met in small working groups to discuss climate-related vulnerabilities in six areas: fisheries; agriculture; community planning, infrastructure and economic development; water resources; biodiversity and endangered species; and public health and safety. On the third day of the Workshop, working-group

participants reconvened to discuss response strategies and develop recommendations for future action. Key findings and recommendations from each working group were presented in plenary during the final day of the Workshop, after which the Chair closed the Workshop with a discussion of common themes and next steps.

### *Plenary Presentations*

Opening ceremonies on Monday, March 3 included video presentations from Vice President Al Gore and Senator Daniel K. Inouye (D-HI) and written statements from Senator Daniel K. Akaka (D-HI), Representative Neil Abercrombie (D-HI) and Representative Patsy T. Mink (D-HI). Their comments highlighted the vulnerability of the Pacific Region to the consequences of climate variability and change, took note of the important role that research about the Region plays in understanding local, regional and global climate processes and impacts, and commended the Workshop organizers, sponsors and participants for their commitment and leadership.

During the opening plenary, the Honorable Maizie Hirono, Lieutenant Governor of the State of Hawai‘i, welcomed Workshop participants and highlighted the importance of establishing an effective connection between the private sector and scientists to help address issues related to climate variability and change. The Lieutenant Governor noted that climate variability and change was a topic of great urgency for the Pacific and noted that there were “few scientific efforts of greater moment” than emerging regional assessment programs like the one the Workshop represented. The Lieutenant Governor highlighted some of the significant contributions that scientists and institutions in Hawai‘i have made to the understanding of climate variability and change, including sustained observations of increasing concentrations of CO<sub>2</sub> on Mauna Loa; leadership in national and international scientific programs (e.g. the Tropical Ocean Global Atmosphere program investigating El Niño; the Hawai‘i Ocean Time Series program designed to enhance understanding of the global carbon cycle; and the continuing efforts of the Intergovernmental Panel on Climate Change). The Lieutenant Governor then delivered a formal Proclamation from Hawai‘i Governor Benjamin Cayetano proclaiming the week of March 2–7, 1998 to be “Climate Awareness Week,” and encouraging the people of Hawai‘i and the Pacific Region to learn more about climate variability and its impact on our lives.

Dr. John A. (Jack) Gibbons, Assistant to the President for Science and Technology (and Director of the White House Office of Science and Technology Policy) presented the Keynote Address. Referring to global climate change as “perhaps the most pervasive and challenging long-term environmental issue that we face as we enter the 21st century,” Dr. Gibbons talked about the importance of understanding local consequences for ecosystems and human communities— translating a global problem into what matters on regional and local scales where “most of the significant consequences will be witnessed.” Dr. Gibbons then provided Workshop participants with an overview of climate that included:

- A historical perspective on “disruptions” in the climate system, including a look at evidence of large-scale changes such as glacial/interglacial periods and shorter-term variations such as the El Niño Southern Oscillation (ENSO) cycle in the tropical Pacific;
- Documentation of the approximately 1.0°F temperature increase observed over the past century and the concomitant rise in global sea level of approximately 4–10 inches during the same period;
- Evidence of the role of human activities in enhancing the global greenhouse effect by adding CO<sub>2</sub> and other greenhouse gases to the atmosphere through the burning of fossil fuels and other industrial activities;
- The consequences of year-to-year variability in the climate system, such as El Niño and the potential benefits of using emerging forecasting capabilities to support decision-making;
- Some of the potential consequences of climate change associated with increasing concentrations of greenhouse gases in the atmosphere (based on model simulations), including accelerated sea-level rise; intensification of the water cycle; and possible changes in the frequency and/or intensity of tropical storms and other extreme events; and,
- Some of the potential actions that he believes should be taken to address the challenges and opportunities presented by climate variability and change, including an increase in scientific understanding of climate change and its relationship to other stresses, particularly at regional scales; continued engagement in international policy discussions; and development and deployment of clean technologies for cost-effective reductions in greenhouse gas emissions, including identifying opportunities for U.S. leadership.

In closing, Dr. Gibbons commended Workshop participants for accepting the challenge of creating a framework for regional assessment of climate issues, and noted that the Workshop was an early step in a sustained effort to understand and cope with the consequences of climate variability and change.

### *A Climate System Perspective*

Following Dr. Gibbons’ remarks, the Workshop heard presentations from four representatives of the scientific community:

- Fred MacKenzie (University of Hawai‘i), who provided some additional comments on the enhanced greenhouse effect and global warming;
- Gerald Meehl (National Center for Atmospheric Research), who highlighted some important patterns of climate variability and change and their consequences for the Pacific, and discussed what the future may hold based upon studies using global climate models;
- Roger Lukas (University of Hawai‘i), who addressed issues related to El Niño and other aspects of seasonal-to-interannual climate variability, and the development of an end-to-end climate prediction program for the Pacific; and,
- Charles (Chip) Guard (Water and Environment Research Institute, University of Guam), who provided examples of the practical applications of seasonal-to-interannual climate predictions based on the experiences of the Pacific ENSO Applications Center (PEAC) during the 1997–1998 El Niño.

Presentations by these panelists were designed to provide Workshop participants with a scientific overview of the climate system, including the nature of processes that determine climate variability and change on a global scale; the regional manifestations of those climate processes; emerging capabilities to forecast climate variability on seasonal and year-to-year time scales, and the potential use of this information to address practical problems; and prospects for assessing the regional consequences of longer-term climate change.

Key points raised during Dr. MacKenzie’s presentation included:

- The possible role of sulfate, soot, and other aerosol particles in producing a regional cooling effect in the Pacific, with particular attention to an anticipated increase in aerosol concentrations associated with fossil fuel emissions (SO<sub>2</sub>), biomass burning and volcanic eruptions. In this context, Dr. MacKenzie highlighted the importance of addressing regional cooling associated with aerosols in model-based projections of climate change in the Western Pacific;
- Projections of sea level changes that would have significant consequences for Pacific Islands, including increased shoreline erosion, saltwater intrusion and a reduction in the volume of groundwater (the freshwater lens) in many islands; and

- The importance of anticipating potential “surprises” in the way the Earth’s climate system responds to global warming associated with greenhouse gases— with particular attention to potentially significant changes in ocean circulation and biological feedbacks, neither of which are adequately represented in current global climate models.

Dr. Meehl described the results of a number of studies using global climate models to highlight potentially important patterns of climate change in the Pacific, including possible changes in El Niño or the persistence of El Niño-like conditions. Using the 1997–1998 El Niño as an example, Dr. Meehl highlighted what such conditions might mean for rainfall, temperature and tropical storms throughout the Pacific. He also informed the Workshop that climate change might also affect longer-term (decadal) patterns of variability in the climate system, such as the Pacific Decadal Oscillation characterized by periods of warmer and cooler sea-surface temperatures that appear to oscillate on timescales of around twenty years, with impacts similar to those associated with the ENSO cycle.

Dr. Meehl used some of his own research on prolonged droughts in Kapingamirangi, and periods of increased tropical storm activity in American Samoa, to highlight the potentially devastating human consequences of projected climate change. Citing the effects of sea-level rise as well, Dr. Meehl suggested we may face creation of “ecological refugees”— individuals and communities forced to leave their homes as a result of changes in climate. Dr. Meehl closed by suggesting steps that could be taken in the near term, including capitalizing on emerging capabilities and early successes in the use of El Niño forecasts to support decision making; enhancing research on decadal patterns of climate variability; and conducting additional research and model-based studies to understand how and in what ways climate change might change El Niño patterns or El Niño-like conditions in the Pacific.

Dr. Roger Lukas introduced Workshop participants to the concept of “end-to-end prediction” of seasonal-to-interannual (year-to-year) climate variability, highlighting three critical elements:

- Large-scale prediction of important climate system processes and properties, such as sea-surface temperature, surface winds, rainfall, sea level, ocean currents and air temperatures;
- Assessment efforts designed to identify the impacts of climate variability, and determine the extent to which those impacts are reflected as regional stresses on resources and sectors such as water resources, fisheries, coral reefs, and public health and safety, particularly

impacts associated with tropical storms and other extreme events; and,

- The practical application of climate predictions in supporting decision-making in the public and private sectors, particularly in the Pacific Region.

In this context, Dr. Lukas provided participants with a useful primer on the ENSO cycle in the tropical Pacific, and associated changes in rainfall, winds and tropical storms; waterborne disease vectors, and ocean temperature and circulation patterns (with implications for coral reefs, fisheries and other coastal and marine resources). Dr. Lukas described the intricate interactions between the ocean and atmosphere that give rise to the ENSO cycle, and reviewed the historical record of ENSO events. He then summarized current capabilities in ENSO prediction and provided a comparison of forecasts and observations of the 1997–1998 El Niño by way of example.

Mr. Chip Guard then shared a story about forecasting drought conditions associated with the 1997–1998 El Niño, in order to provide an overview of the challenges and opportunities of using forecasts of year-to-year climate variability in the Pacific. He began with an overview of the PEAC, a joint effort involving the National Oceanic and Atmospheric Administration (through its Office of Global Programs, and the National Weather Service’s Pacific Region Office), the University of Hawai‘i (through its Social Science Research Institute, and School of Ocean and Earth Sciences and Technology), and the University of Guam’s Water and Environment Research Institute. Since 1994, PEAC has provided forecasts of El Niño for U.S.-affiliated Pacific Island jurisdictions and supported a complementary program of education and outreach designed to promote practical use of those forecasts in activities like emergency preparedness and water resource management. In describing the PEAC experience, Mr. Guard emphasized the importance of combining observations with model-based forecasts and local insights, i.e., a team effort that capitalizes on the special expertise and unique capabilities of individuals and institutions working toward a common goal— the development, provision and application of climate forecasts for the benefit of Pacific Island jurisdictions.

During his presentation, Mr. Guard highlighted a number of valuable lessons learned from the PEAC experience, including:

- The importance of forecasting not only the onset, duration and intensity of ENSO events, but also, to the extent possible, the specific impacts that might be anticipated, particularly changes in rainfall and tropical storms;

- The value of using historical analogs (i.e., comparisons with similar ENSO events in the past) to help scientists and users understand what to expect;
- The challenge and importance of making scientific information understandable, useful and usable;
- The need to develop a clear understanding of both impacts and available response options, with an eye toward understanding (and addressing) the scientific, technical, institutional and policy constraints (and opportunities) on the use of climate forecasts; and,
- The importance of sustained face-to-face interaction between scientists, forecasters and users of climate forecast information in governments, businesses and communities—a sustained dialogue that promotes shared learning and joint problem-solving.

### *A Community Planning and Economic Development Perspective*

A second panel provided Workshop participants with a view of climate variability and change from the perspective of people who represented what the panel Chair called “users of scientific information,” noting that their livelihoods and that of their employees and customers are affected by climate variability and change. This perspective was presented by:

- Robin Campaniano (AIG Insurance Hawai‘i);
- Robert Fraser Ripp (GST Telecom Hawai‘i);
- Richard Cox, Hawai‘i State Water Commission; and,
- Richard Ha, President of Kea‘au Banana Farms.

This second panel was organized to provide an overview of some critical regional issues in community planning and economic development; particular attention was given to sectors and communities that are sensitive to climate variability and change, and the goal was to identify opportunities to improve decision-making through the use of new scientific information.

Mr. Robin Campaniano provided insights into how and why climate matters to individuals and businesses concerned with insurance. He specifically highlighted the challenges of providing property and casualty insurance in areas subject to natural hazards such as hurricanes and tropical storms. Referring specifically to wind damage from storms, Mr. Campaniano described the importance of current efforts to reduce damages—through better building codes, for example— but also noted the potential benefits associated with improving emergency planning and preparedness through incorporation of information on climate variability (particularly El Niño) and change. In this context, he suggested that the insurance industry’s interests in climate change would most likely involve issues such as:

- Hurricanes and storm surge;
- Flooding;
- Agricultural losses;
- Health effects; and,
- Economic losses from business interruptions (such as those suffered on the island of Kaua‘i following Hurricane Iniki).

Mr. Campaniano specifically mentioned the emergence of catastrophic-loss-modeling as an important new tool in the insurance sector, and suggested that incorporation of climate information and projections in those models might offer important improvements (e.g., more equitable premium prices that reflect areas of greater or lower risk, to avoid discounting or inflating the true cost of coverage). While acknowledging these opportunities, Mr. Campaniano cautioned that there are significant scientific, institutional, economic and ethical challenges associated with changes to the way in which the insurance industry does business. He noted specifically the need to address the timeliness and accuracy of climate predictions, as well as the evaluation of response options. In conclusion, he noted that it was “economically essential that we develop a more complete understanding of climate events.”

Mr. Robert Ripp provided some insights into the importance of climate information for the telecommunications industry, noting the dual role of telecommunications in both collecting data and communicating information. Mr. Ripp pointed out that telecommunications businesses are primarily concerned with avoiding service interruptions associated with disturbances such as winds. He added that understanding weather and atmospheric conditions is vital to planning decisions regarding what type of systems to install (e.g., choosing fiber optics or satellite options vs. microwave systems, which are more vulnerable to wind disturbances). Mr. Ripp noted that these could be “life or death decisions” for both companies and communities, particularly in isolated island settings. In addition to system design and planning decisions, Mr. Ripp also discussed Hurricane Iniki to highlight the potential benefit of improved weather and climate information in supporting decisions about positioning fall-back systems. In summary, he said that information about climate variability and change would be important for both strategic planning and disaster preparedness in the telecommunications sector.

Mr. Richard Cox spoke from the perspective of someone who has been involved in water resource management, providing interesting insights into how and why climate matters in that sector. He began his comments by noting that current climate conditions (including issues related to



natural variability like ENSO) are already concerns for communities and businesses, and highlighted the importance of understanding what changes are likely to occur, and what steps would be appropriate to build systems that can adjust to those changing conditions. Mr. Cox noted that weather and climate information and research are already important to the water sector (e.g., hurricane and drought forecasting and preparedness). He noted that changes in rainfall, tropical storms and other extreme events, sea-level rise, and increasing temperatures, were important issues from a water resources perspective. He also identified some related issues that could benefit from enhanced information on climate variability and change, including:

- Incorporation of information about climate-related natural hazards into planning for major new facilities and developments (e.g., information on changing patterns of tropical storms, or changes in rainfall patterns that could affect flooding and slope stability); and,
- Improved information on rainfall and water resources for agriculture, which he noted is the largest consumer of water on all Hawaiian islands except O‘ahu.

Mr. Cox noted that most decisions about water resources are based on historical rainfall data and long-term averages, and suggested that some consideration be given to incorporating emerging forecasting capabilities (like El Niño forecasts) and new insights about the possible consequences of climate change; he said information on climate variability and change might, for example, be useful in reassessing aquifer capacities. In addition, he said that exploring the direct and indirect consequences of climate variability and change could help resolve possible response conflicts by providing an opportunity to conduct “what if” scenarios to identify problem areas and review response options (such as water reuse and conservation measures). Noting that he is naturally somewhat conservative or skeptical about new ideas and projections of future conditions, he emphasized the importance of conducting more research on climate variability and change, and sustaining a dialogue among government agencies, businesses, scientists and communities in order both to anticipate what might happen and to develop effective response strategies.

Richard Ha provided Workshop participants with insights into climate and weather from the perspective of a commercial farmer in Hawai‘i. He started his presentation by highlighting the importance of agriculture’s contribution to Hawai‘i’s economy: an annual contribution of \$.5 billion in direct crop value, and a value-added contribution of \$1 billion. Mr. Ha provided a brief description of his banana farming enterprise, noting the critical importance of the

abundant rainfall that “irrigates” his Big Island farm (130 inches/year, compared to Hawai‘i’s average of 32 inches/year); this translates into 3.5 billion gallons/acre/year of “free water” for his farm. He added that when he considered expanding his activities on either the Big Island or O‘ahu (which is closer to markets), his decision “turned on water” and led him to expand his Big Island site.

Mr. Ha acknowledged that anticipation of drought is a persistent factor in farm operations, and said he recently installed an irrigation system (in-ground pipes and drip tape). This irrigation system allows him to prepare for droughts and reduce losses and, in fact, helped him minimize the effects of the dry conditions associated with the 1997–1998 El Niño. This same irrigation system can also provide him with the flexibility to diversify by growing other crops when rains are abundant. He expressed a specific interest in having access to climate forecast information (such as El Niño forecasts) to further enhance his ability to prepare for and deal with droughts and other extreme events. He went on to say that hurricanes are also an important factor in a farmer’s decisions— noting that “we expect drought and we expect to get flattened” periodically. As a result, better information about what climate variability and change might mean for hurricanes would also be useful to the agricultural sector.

#### *A Habitat and Natural Resources Perspective*

A third panel looked at the implications of climate variability and change for critical habitats and unique natural resources in Pacific Island settings. This perspective was presented by:

- Oliver Chadwick, University of California at Santa Barbara;
- Peter Vitousek, Stanford University; and,
- Ray Carter, CASAMAR, Guam.

This final panel of the opening day was organized to provide an overview of key issues related to the unique ecosystems and resources of the region, including how climate variability and change interacts with human activities such as land use to affect biodiversity; what can be learned from islands as models of climate change; and what the implications are for climate variability and change for critical resources such as water and fisheries.

Dr. Chadwick cited his work on the Big Island to offer some insights into the importance of island settings in helping to understand ecosystem processes and climate/ ecosystem interactions. He noted that climate is one of the systems that can be analyzed when studying ecosystems (along with specific organisms, topical relief, parent

material and time). He said the 'ohi'a tree is the dominant plant species in his study area, which simplifies his choice of an organism to study. And because the parent material (a lava base) is pretty much the same everywhere in the area, and as a result, time can be calculated pretty accurately by determining distance (time) from the geologic hotspot that gave rise to the Hawaiian islands, he has the opportunity to focus on determining and understanding how changes in climatic conditions might account for historic and current variations in 'ohi'a in different parts of the island; he noted in particular the value of marked changes in rainfall conditions at different elevations along the Big Island's mountain slopes.

Focusing specifically on rainfall as a key climate factor, Dr. Chadwick noted that the Big Island is characterized by diverse environmental conditions above and below the inversion layer, which lies at about 7,000 feet and marks a transition to a relative "polar desert" at the top of Mauna Kea. He also noted that there are two principal sources of rainfall that affect vegetation on the Big Island— storms carried by tradewinds that do not get over the mountains, and cyclonic storms (Kona storms) that bring rain to all parts of the island. Understanding (and comparing) the vegetation regimes that result from these two different sources of rainfall can help clarify how vegetation and ecosystems might vary in response to climate-induced changes in rainfall patterns. He cautioned, however, that his research has revealed a high variability in rainfall at some sites, and suggested that this variability might justify reconsidering concepts like "median rainfall," which is commonly used in climate-vegetation studies. Dr. Chadwick closed his remarks by suggesting that Hawai'i and Pacific Islands in general could be called a "microcosm of nature" with very few external factors to complicate studies of how and why climate matters to island ecosystems.

Dr. Peter Vitousek offered some thoughts on what his research on certain bird species in Hawai'i suggests about the consequences of climate variability and change. He began his discussion by noting that climate change is only one of a number of important factors affecting ecosystem and species change, including land-use change, biological invasions/exotic species, and biodiversity. He noted, for example, how changes in land cover associated with agricultural activity have been a factor throughout Hawai'i's history. Dr. Vitousek also emphasized the importance of understanding the interplay among these various factors as well as understanding individual factors like climate change.

He offered a specific example from his own research, which has clarified how the range of certain native bird species is now determined in part by temperature constraints on an

introduced species of mosquito that serves as a vector for a particularly virulent form of avian malaria. Populations of these birds now tend to be concentrated at higher elevations where temperatures aren't warm enough to sustain the mosquito populations. Dr. Vitousek noted that increasing temperatures associated with climate change might allow the mosquito populations to move upslope, exposing native birds to additional malaria risk with potentially devastating effects; these effects are particularly likely if the birds are forced so far upslope that they encounter a loss of habitat beyond the "hard boundary" where forested areas give way to pasture lands toward the top of Mauna Kea. He added that on the island of Kaua'i, the situation is a bit worse because there is no area that would fall above the survivability threshold for the mosquitoes that carry avian malaria. In contrast, the island of Maui contains sufficient upslope forest to provide habitat for birds as temperature increases and populations move higher.

Dr. Vitousek noted that his research reinforces the importance of considering the impacts of and responses to climate change in the context of other stresses such as land-use change. While variations in climate have occurred in the past— with species and ecosystems adapting and changing in response— many species may find the combination of climate change with other stresses (like biological invasions and land transformations) impossible to accommodate. Recalling Dr. Chadwick's comments, Dr. Vitousek reminded Workshop participants that understanding and responding to the consequences of climate change in islands could provide valuable models for scientists and decision-makers in other regions.

Mr. Ray Carter used the results of some recent work on the impacts of the 1997–1998 El Niño on Pacific tuna fisheries to provide insights into the relationship of climate to this important component of Pacific Island economies; his work has been conducted in collaboration with Dr. Michael Hamnett and Ms. Cheryl Anderson at the University of Hawai'i. As Mr. Carter noted, commercially important stocks of yellowfin and skipjack tuna are highly migratory species whose behavior responds, in part, to climate variations such as El Niño. Confirming previous work by others, Mr. Carter's catch statistics indicate that El Niño-related increases in ocean temperature in the Eastern Pacific were associated with an eastward shift in the catch of tuna; he cited specific examples drawn from areas around the Federated States of Micronesia. In explanation, he said the temperature of the water affects the availability of food organisms, which, in turn, affects the tuna stocks.

This eastward shift in stock distribution can have significant economic implications. A shift out of a country's

Exclusive Economic Zone, for example, means less income from license fees for Distant Water Fishing Nations. Similarly, changes in stock distribution can affect the level of effort (and income) that must be expended by canneries or transshipment facilities; conversely, knowledge of stock distribution can help those facilities prepare for either enhanced opportunities or reductions in business. In addition, information about the effect of climate change on tuna stocks would be important for island businesses and governments planning to install new transshipment facilities or canneries, or anticipating the emergence of tuna fisheries as an important source of income. Mr. Carter noted that his data also showed a change in species composition — an increase in more valuable stocks of yellowfin with a decrease in skipjack stocks. Thus, while overall catch in the region was down, the economic value for an individual vessel might have been even.

Mr. Carter emphasized that while his research, and that of others, clearly shows a link between climate and tuna, there is a need for considerably more data and research. Enhanced information about how climate variability like El Niño affects commercially important tuna stocks from one year to the next could be extremely valuable to businesses and governments throughout the Pacific. Similarly, a better understanding of how climate change might affect stock distribution could help inform important decisions about the role tuna fisheries can play in the future Pacific Island economies.

### *Working Group Discussions of Vulnerability and Response Strategies*

On the second and third days of the Workshop, participants convened in small working groups for an in-depth exploration of regional vulnerabilities to climate variability and change, and discussions of near- and long-term strategies for response to climate variability and change for different sectors and communities. On the second day of the Workshop, participants considered climate-related vulnerabilities in six areas:

- Fisheries— including issues for commercial and recreational fisheries, coastal and marine habitats, and the concerns and rights of indigenous peoples;
- Agriculture— including issues for commercial agriculture, ranching and subsistence farming;
- Community Planning, Infrastructure and Economic Development— including issues for tourism and recreation, energy, transportation, housing, communications, and industry;
- Water Resources— including issues of fresh water availability, access and management;

- Biodiversity and Endangered Species— including issues of species protection, ecosystem conservation and management, resource development, tourism, and the cultural concerns and rights of indigenous peoples; and,
- Public Health and Safety— including issues of climate-related changes in water- and vector-borne diseases, air and water quality, and health and safety as it relates to natural hazards like hurricanes and tropical storms.

Following guidelines provided to all regional workshops within the U.S. National Assessment, participants were asked to address the following:

- What issues concern you (your sector) today?
- In what way are these issues (your sector) sensitive to climate variability and change? and,
- What challenges do affected businesses, communities and ecosystems face in reducing risks or capitalizing on opportunities associated with climate variability and change?

On the third day of the Workshop, participants discussed response strategies that provide an opportunity to:

- Identify critical information needs;
- Explore ways to overcome obstacles that inhibit the use of climate information to support decision-making in various sectors; and
- Recommend near- and long-term actions that could remove those obstacles.

These working groups were asked to evaluate scientific and technical gaps in understanding (What should we know that we don't?); institutional and policy barriers to effective use of climate information (Are changes required in policies or in public and private institutions to enhance decision-making); and limitations on our ability to convey and apply new scientific insights and research results (How can we improve the dialogue between scientists and key decision-makers?).

### *Key Findings and Recommendations*

Following a review of the findings and recommendations contained in the final working group reports, the Chair summarized key findings and recommendations under three categories:

- Vulnerability issues common to all working groups and jurisdictions in the Pacific region;
- Shared principles that could guide the development of effective response strategies; and,
- Critical information needs that should help shape future research.

## Common Vulnerability Issues

- Climate variability and change are superimposed on many other stresses, but information on interactions and feedbacks is often lacking;
- In all sectors, year-to-year climate variability such as that associated with ENSO and extreme events already poses significant challenges to communities, businesses, governments and resource managers throughout the region— and it is essential to understand how this variability might change;
- The geographic size and isolation of island communities creates special circumstances (e.g., limited land and water) and may constrain response options, while conversely, island communities can be “models” for understanding and responding to the consequences of climate variability and change;
- The absence of a long-term, strategic planning structure or management vision enhances vulnerabilities in most sectors;
- Required data sets are often missing or inaccessible, including biological and socioeconomic data and information on the physical environment;
- Monitoring, research and modeling programs are essential;
- Localized research is critical but difficult to support;
- There is an absence of research on the consequences and costs of mitigation options.
- Infrastructure and community support services are already stressed in most areas, and there is a need for additional vulnerability assessments;
- Integration of climate information in decision-making is limited and often based on historical data, creating a demonstrable need to anticipate conditions and incorporate emerging predictive capabilities and new scientific insights; and
- Scientific, institutional and communication barriers are creating an information gap between scientists studying climate variability and change and the intended users/potential beneficiaries in governments, businesses and communities.

## Shared Principles for the Design of Response Strategies

- Take advantage of and build on previous and ongoing efforts to identify and address the consequences of climate variability and change for island states and communities and start by linking existing institutions and programs;
- Start by enhancing access to currently available data while new information is being developed; there is value in what we have now so get it out there (e.g., integrating ENSO forecasts into decision making now);
- Appropriate response strategies should recognize and respect differences among political, cultural, economic

and natural systems in the region as well as the unique circumstances of island communities and the special insights of local (indigenous) peoples;

- Management and policy options should be flexible in order to adapt to year-to-year natural variability in the climate system and accommodate potential surprises;
- Effective responses require strengthened and new partnerships involving scientists/scientific institutions, businesses, governments and communities;
- Proactive (precautionary) rather than reactive approaches are preferred—integrate climate information into decisions on a regular and continuing basis;
- Look for future opportunities while addressing today’s problems;
- Enhance education activities – formal and informal education programs; address all ages; including information on both anticipated changes and response options;
- Identify, secure and sustain the necessary human and financial resources;
- Involve information users in the development of new climate information products; users and providers should regularly (and jointly) evaluate the usefulness and usability of climate information products and assess progress; and, finally,
- A continuing, interactive dialogue among scientists and decision makers in the public and private sectors is essential; this requires a sustained commitment to the translation and communication of research results and an effective program of outreach and education... this may require the creation of new institutional arrangements.

## Critical Information Needs

- Regular and reliable access to emerging forecasting capabilities on year-to-year time scales;
- Improved understanding of the physical, social and economic implications of climate variability and change for key sectors to support near-term decision making and long-term planning;
- Improved understanding of regional trends in demographics and economic development to support local/regional planning and assess the consequences of climate variability and change;
- Improved understanding of the effects of climate variability and change on unique (Pacific) island ecosystems, critical habitats and key species in the region;
- Improved understanding of the health-related consequences of climate variability and change in the region; and
- Maintenance of a continuing dialogue among scientists and public and private sector interests to identify changing information needs, support decision-making and take advantage of new scientific insights and emerging technologies.

### *Next Steps*

The March 1998 Workshop participants identified a number of next steps which have subsequently been pursued by the Workshop organizers and sponsors in the context of a Pacific Islands regional contribution to the first National Assessment of the Consequences of Climate Variability and Change for the United States. The key findings and recommendations from the March 1998 Workshop were provided to the National Assessment Synthesis Team and used to design an 18-month initial Pacific Islands Regional Assessment Project. Funding for this initial assessment project was provided to the East-West Center (Honolulu, HI) through a grant from the National Science Foundation (NSF) on behalf of NSF, NOAA, NASA and the Department of the Interior. The project is scheduled to be completed at the end of calendar year 2000.

Building on the findings and recommendations of the March 1998 Workshop, the initial Pacific Islands Regional Assessment has been organized to achieve the overarching goal of nurturing the critical partnerships necessary to develop and use climate information to enhance the ability of scientists and decision makers throughout the Pacific to understand and respond to the challenges and opportunities presented by climate variability and change.

Based on the findings of the March 1998 Workshop, highest priority in the Pacific Islands Regional Assessment is being given to: water resources; public health and safety (with an emphasis on extreme events); and the special challenges of climate variability and change for island coastal communities and ecosystems.

Like the March 1998 Workshop and the National Assessment, the Pacific Islands Regional Assessment is pursuing dual, mutually reinforcing objectives:

- Conducting research and analysis to develop a more complete understanding of regional consequences; and
- Initiating and sustaining an interactive dialogue to support decision-making.

This latter objective responds to the March 1998 Workshop's call to maintain the momentum initiated by that gathering and establish a regional network of individuals and institutions who will: further explore the consequences of climate variability and change for communities, businesses, governments and natural systems; identify and pursue opportunities for long-term partnerships to support the development and use of climate information; and identify and pursue opportunities for near- and long-term support for ongoing and new programs and the develop-

ment of new institutional capabilities. In this context, the initial Pacific Islands Regional Assessment is supporting a series of workshops and small-group meetings ("roundtable discussions") designed to provide opportunities for in-depth exploration of how and why climate variability and change matter for key sectors (e.g., tourism), resources (e.g., coastal resources, water resources) and communities (e.g., the Native Hawaiian community). The process of shared learning and joint problem solving characterized by this program of outreach and education is the programmatic backbone of the emerging Pacific Islands Regional Assessment. The Assessment process is providing the central support structure around which a new, regional climate information service is taking shape—a service that responds to the findings and recommendations of the March 1998 Workshop.



## Workshop Steering Committee

*Workshop on the Consequences of Climate Variability and Change for Hawai‘i and the Pacific: Challenges and Opportunities*

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<sup>1</sup> In Mr. Blanco's absence, the Governor's Office was represented by Mr. Kelvin Char, of the National Oceanic and Atmospheric Administration, who was on an Intergovernmental Personnel Act assignment to the Governor's Office.

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<sup>4</sup>These individuals were responsible for leading discussions of regional climate vulnerability during the March 1998 Workshop; the reports of their deliberations provided a foundation for the final Pacific Islands Regional Assessment Report.

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## APPENDIX F— PROCLAMATION BY THE GOVERNOR OF HAWAII

